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WASTEWATER RECLAMATION PROJECT, ST. CROIX, U.S. VIRGIN ISLANDS

BLACK, CROW AND EIDSNESS, INCORPORATED

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MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY

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16. ABSTRACT

St. Croix is a subtropical semiarid island in the Territory of the U.S. Virgin Islands. The expanding population and rising standard of living have resulted in a level of potable water consumption above the available supply of surface and groundwater. Seawater desalinization plants are currently being used to produce the needed water. The cost of this desalinized water ranges up to $7/thousand gal ($1.84/cu m).

Since 1971 work has been proceeding on a project to use tertiary-treated wastewater effluent for artificial recharge of the groundwater on St. Croix. A 0.5 mgd (1,890 cu m/day) advanced wastewater treatment plant and recharge facilities were designed and constructed. Background data on water quality and quantity in the surrounding area were collected for 2-1/2 years before recharging began. Recharge operations were carried out for 8 months during 1974, using both spray irrigation and spreading basins. The best method of recharging proved to be the use of spreading basins in an alluvial valley. The cost for the wastewater treatment, recharge operations, and recovery of groundwater was estimated to be about $2.15/thousand gal ($0.57/cu m) at 0.5 mgd (1,890 cu m/day) with a reduction in estimated costs to $1.64/thousand gal ($0.43/cu m) if the operation is expanded to 1 mgd (3,785 cu m/day).

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The study described here was undertaken to demonstrate the reuse of municipal wastewater as a means of conserving valuable water resources in a water-short semi-arid area by recharging groundwater supplies with treated effluents.

Francis T. Mayo
Director
Municipal Environmental
Research Laboratory

PREFACE

With a burgeoning population and a concomitant insufficiency of potable water, the United States Virgin Islands is continually faced with the necessity of constructing additional desalinization plants. The freshwater supply is a combination of rainwater collected in cisterns, a rather meager amount of groundwater, and a rather large proportion of desalinated water. To conserve potable water, saltwater flushing is resorted to in some areas. Since the rainfall is unpredictable and highly nonuniform during the year, with either substantial rain or none at all for months at a time, the aquifers are generally either full or empty.

Because of the tremendous importance of the water problem, with its social and economic implications, it is obvious that any reasonable alternative to a once-through-use-and-discharge-to-the-ocean must be investigated. In the present work, recharge of suitably treated wastewater is addressed experimentally. The selection and preparation of a recharge site, study of the nature of the aquifer, and techniques of recharge are all discussed against the background of a semiarid, subtropical island environment.

As a comprehensive geologic and sanitary engineering study of St. Croix from the standpoint of groundwater recharge, this report will serve as a foundation for the development of a water management master plan for the island, as well as the model for studies of other similar islands and selected coastal areas.

Robert W. Mason, Ph.D.
Research and Development
Representative, Region II

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ABBREVIATIONS AND SYMBOLS

Standard Abbreviations

AWWTP	Advanced wastewater treatment plant
BOD	Five-day biochemical oxygen demand
C	Centigrade
cm	Centimeters
cu	Cubic
E	Estate Envy
EPA	Environmental Protection Agency
FCR	Free chlorine residual
ft	Feet
FTU	Formazin turbidity units
gal	Gallons
gpcd	Gallons per capita per day
gpd	Gallons per day
gpm	Gallons per minute
ha	Hectares
in.	Inches
kg	Kilograms
km	Kilometers
l	Liters
lb	Pounds
m	Meters
mgd	Million gallons per day
mg	Milligrams

mil gal	Million gallons
MLSS	Mixed liquor suspended solids
PVC	Polyvinyl chloride
PWD	Public Works Department
SAR	Sodium absorption ratio
sec	Seconds
sq	Square
Std Dev	Standard deviation
SVI	Sludge volume index
TDS	Total dissolved solids
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
V.I.	Virgin Islands
WAPA	Water and Power Authority
wk	Weeks

Well Abbreviations and Symbols

A	Adventure
BMW	Bethlehem Middle Works
E	Envy
F	Fountain
FP	Fair Plains
GG	Golden Grove
GP	Grove Place
LL	Lower Love
MB	Manning Bay

▲	Rain gage
●	Public well--pumped
◓	Public well--not pumped
■	Private well--pumped
⬒	Private well--not pumped
⬢	Sampling station on a stream

SECTION I

INTRODUCTION

DESCRIPTION OF ST. CROIX

St. Croix is the largest of the more than 50 islands and cays which comprise the Territory of the U.S. Virgin Islands. The Virgin Islands are located 1,100 miles (1,770 km) southeast of Miami, Florida, and have been a possession of the United States since 1917 when they were purchased from Denmark (see Figure 1).

St. Croix is 84 sq miles (217 sq km) in area. It is about 20 miles (32.2 km) long and 6 miles (9.6 km) wide at its broadest point (see Figure 2). A range of low mountains forms a spine along its longer east-west axis. The Northside Range at the western half of the island hugs the northern shore and a flat coastal plain has been formed from the foothills of the range to the south shore. It is on this coastal plain between the two major towns of Frederiksted and Christiansted that the majority of the people of the island live. The island has about 40,000 inhabitants and the major sources of employment are in alumina processing, petroleum refining, watch assembling, tourist-related services, or government agencies. Agriculture, which used to be the largest source of income on the island, has dwindled considerably in the last decade. The growing of sugarcane has been phased out, leaving beef cattle and dairy products as the major agricultural enterprises.

In the latter part of the eighteenth century when agriculture was the only industry, the entire island was divided up into plots of about 150 to 300 acres (61 to 122 ha). Each plot was called an estate and given a name. This system of estate division remains today and forms an important function in the location of any point on the island. These names, such as Golden Grove, Adventure, and Negro Bay, are used throughout this report to aid in the location of areas for those familiar with the island.

Water Supply

Along with this shift from a rural agricultural economy towards industrial growth and tourism, there has been a rapid increase in population and a rise in the standard of living. With these changes has come a massive increase in total water consumption. Unfortunately the low topography of the island does not promote the

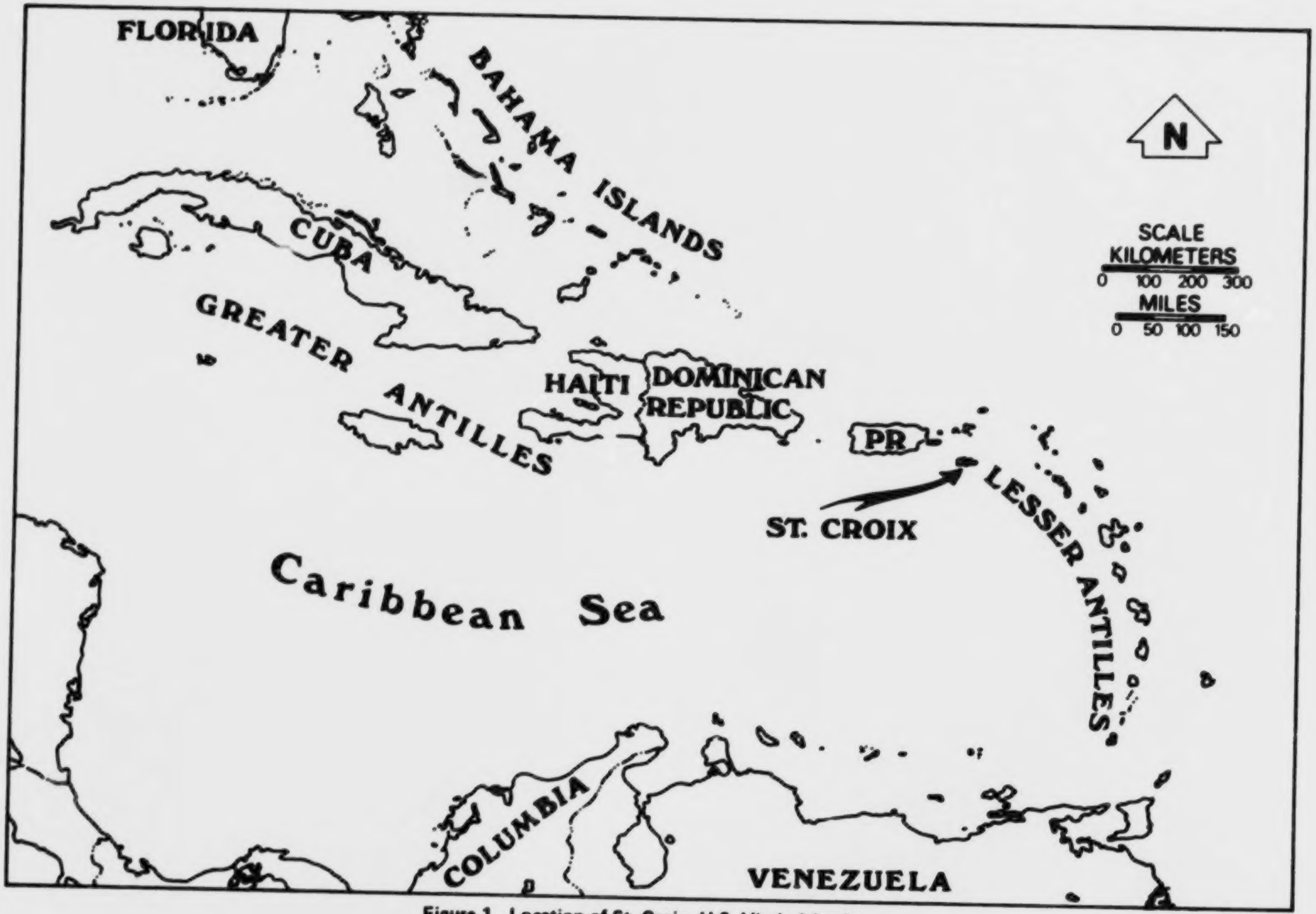
FLORIDA
BAHAMA ISLANDS
CUBA
GREATER ANTILLES
HAITI
DOMINICAN REPUBLIC
PR
ST. CROIX
LESSER ANTILLES
Caribbean Sea
COLUMBIA
VENEZUELA
N
SCALE
KILOMETERS
0 100 200 300
MILES
0 50 100 150

Figure 1. Location of St. Croix, U.S. Virgin Islands.

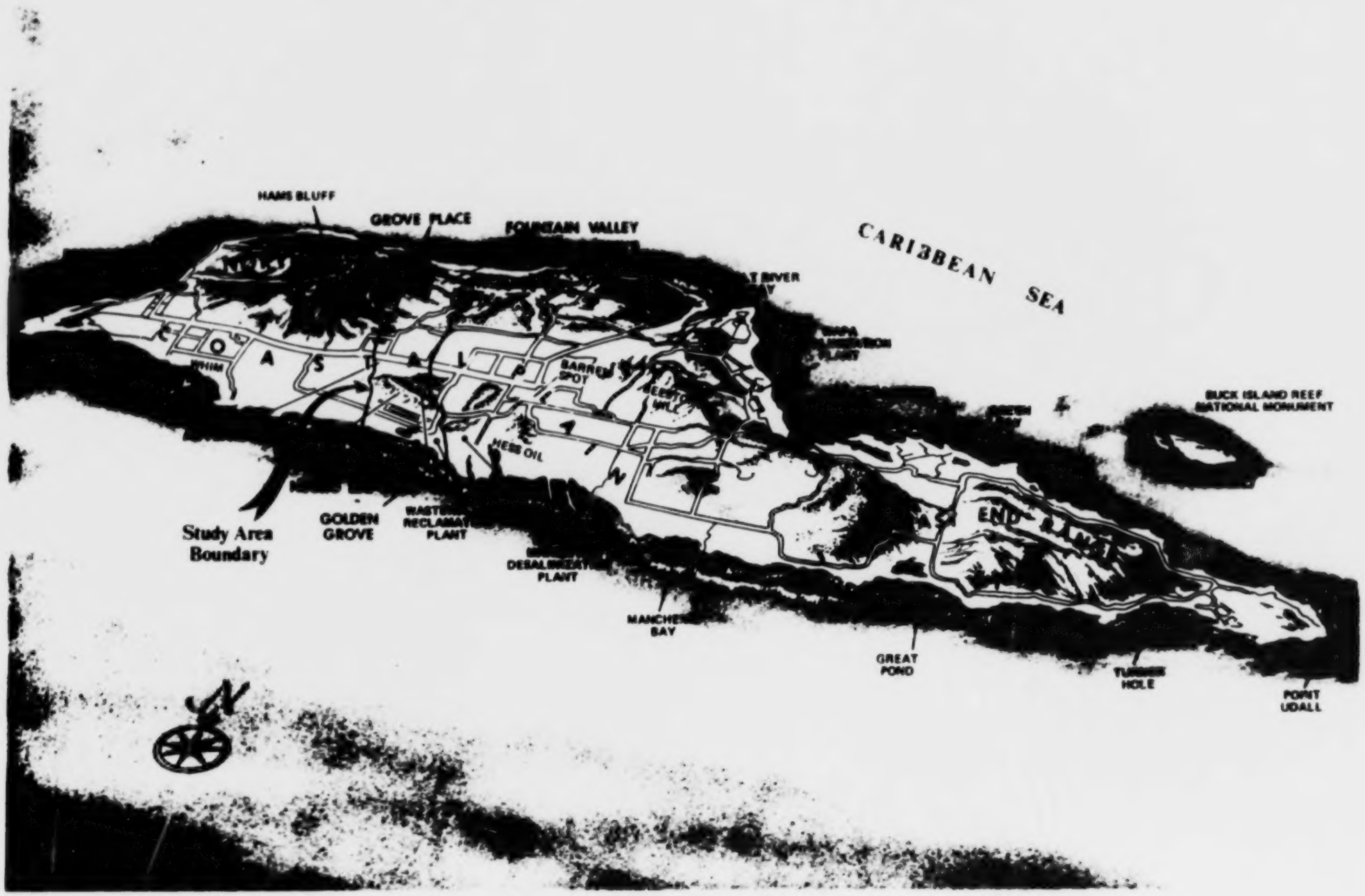
HAMS BLUFF
GROVE PLACE
FOUNTAIN VALLEY
CARIBBEAN SEA
WHIM
COASTAL PLAIN
BARREN SPOT
HESS OIL
GOLDEN GROVE
WASTE RECLAMATION PLANT
DESALINIZATION PLANT
MANCHENIL BAY
GREAT POND
EAST END RANGE
BUCK ISLAND REEF NATIONAL MONUMENT
TURNER HOLE
POINT UDALL
Study Area Boundary
N

Figure 2. St. Croix, U.S. Virgin Islands.

formation of rain clouds as reliably as on the larger, higher islands in the Caribbean. The average rainfall is only 40 to 45 in. (102 to 114 cm) per year. This combined with the extremely high evapotranspiration rate restricts the amount of surface and groundwater on the island available for water supply usage.

Although each dwelling is still required by law to be constructed so as to catch and store the rainwater from its roof as a basic source of water, it has been necessary for the government to augment this supply through a water distribution system. This additional water was originally derived from wells located in the central part of St. Croix, and is now supplemented by large seawater desalinization plants located in Christiansted and mid-island at the Martin Marietta Alumina Company.

The combination of rainwater catchments and groundwater could go a long way in satisfying the demand for water on the island, but they are very much dependent on the pattern of weather in the area. In the past few years this pattern has tended to minimize the benefits to be derived, directly or indirectly, from the rainfall. Figure 3 compares rainfall and the water levels in two wells in central St. Croix over the past 4 years. Although the average rainfall over this short period approaches the norm expected, the distribution of rainfall throughout the individual years has made it difficult for efficient cistern storage and has detrimentally affected the efficient natural recharge of the groundwater.

The combination of reduced rainfall, a diminished groundwater supply, and increased individual consumption has caused the demand to exceed the production of water from these traditional sources. Although only about 70 percent of the populace is connected to the public distribution system, it has been necessary to use increasing amounts of desalinized water in the system until presently the groundwater contribution to the total water supply picture is only about 30 percent. This is discussed in further detail in Section V under the topic, Water and Wastewater Systems on the Island.

The desalinized water for the potable system is produced by two distillation plants, one operated by the Virgin Islands Water and Power Authority (WAPA) and the other by the Martin Marietta Alumina Company. Each provides about 0.65 mgd (2,460 cu m/day) to the system. The average amount of water being distributed in the public system during the spring of 1975 was about 1.8 mgd (6,813 cu m/day).

This amount represents the supply and not the demand, as the demand for water exceeds this figure by possibly as much as 30 percent for just the existing hookups. Additionally, in the past year or so at least 14 miles (22.5 km) of water mains have been added to the system. Connections to these new mains have been almost nil as there is insufficient water in the system to properly service any new consumers. It has been quite normal to wait 2 to 3 years for

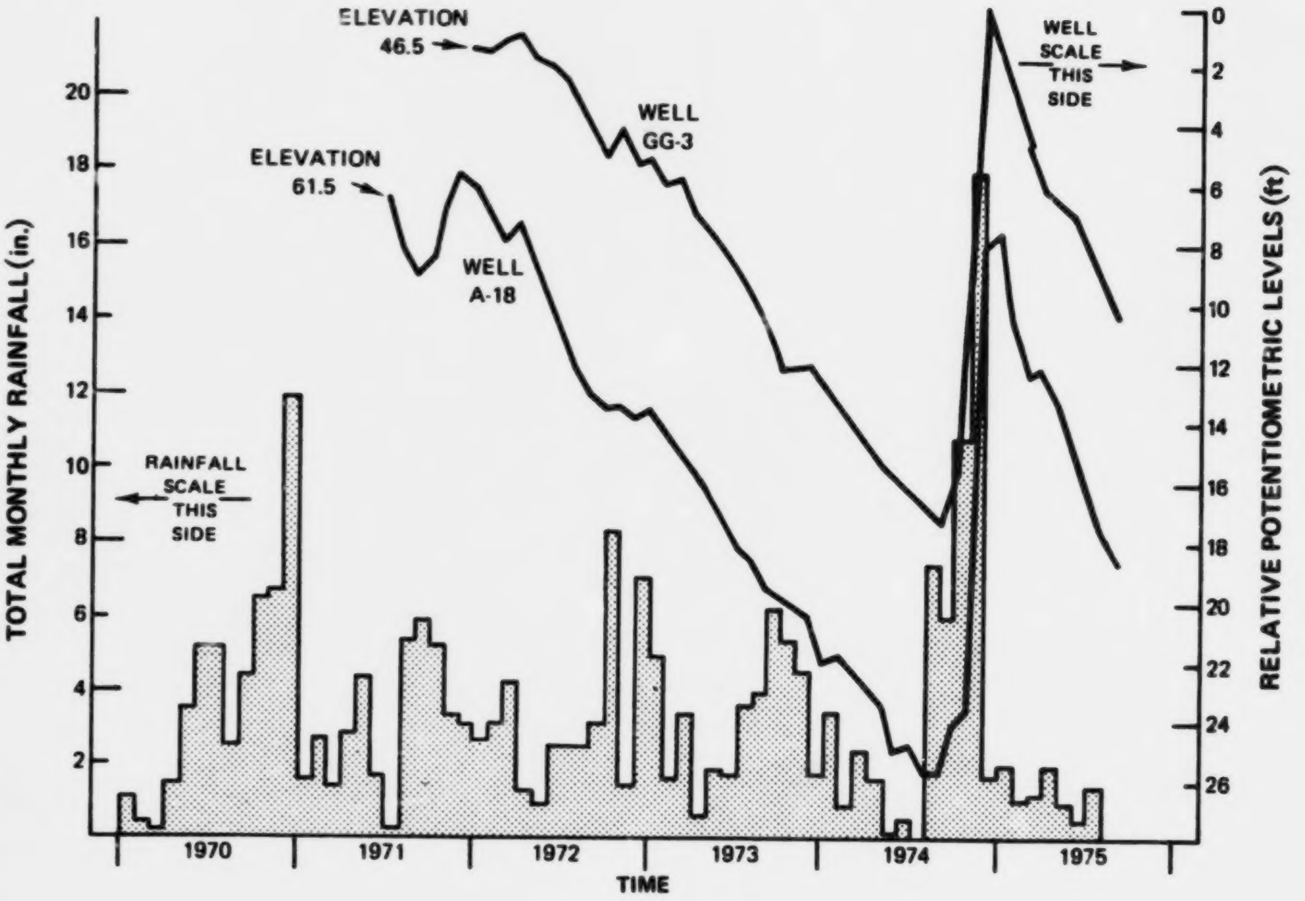

Figure 3. Rainfall and groundwater potentiometric levels in central St. Croix.

individual homes to obtain permission to hook up to the potable distribution system and even after the connection is made there is no assurance that a steady supply of water will be available.

Water Costs

As the price of petroleum has increased so has the cost of producing desalinized water, which requires oil-fired boilers to produce the steam used in the distillation process. Since almost two-thirds of the water in the public potable system is derived from distillation plants the aggregate cost has increased drastically. The changing cost to the public system for this water over the past three years is shown in Figure 4. This shows the cost to the government from both the WAPA and the Martin Marietta plants. In June, 1975, the cost of water from these plants was \$5.16/thousand gal (\$1.36/cu m) and \$6.86/thousand gal (\$1.81 cu m) respectively, for an average of 0.75 mgd (2,839 cu m/day). This is compared to the estimated cost of \$0.30/thousand gal (\$0.08/cu m) for groundwater produced on the island.

Although water is sold to the general public for \$4.00/thousand gal (\$1.05/cu m), which is about ten times the cost in the mainland United States, the government is still losing money in distributing it due to the high proportion of expensive desalinized water used.

At present the WAPA is increasing its water supply capacity by the construction of a new 2.25 mgd (8,516 cu m/day) desalting plant which should be on line sometime in the latter part of 1975. Although this could possibly give the island a surplus of water, it is realized that the Martin Marietta Alumina Company will soon be phasing out its sales of water to the government and that in the past the consumer demand has always risen to match the amount of water that the government has been able to distribute.

Water Reuse

With the water supply system based mainly on desalted water, the water is converted from seawater to fresh water at great expense, used once, and then returned to the ocean as wastewater. Not only is it expensive, but also the expansion of the desalination facilities creates a situation where there is a greater dependency upon water from a single source instead of the more versatile multiple-source concept which the island still possesses. If this desalted water could be used once, processed for reuse, and utilized again before being completely degraded by discharge back into the ocean, the cost of the processing between uses should be significantly below the expense currently required to recover fresh water from the ocean by distillation.

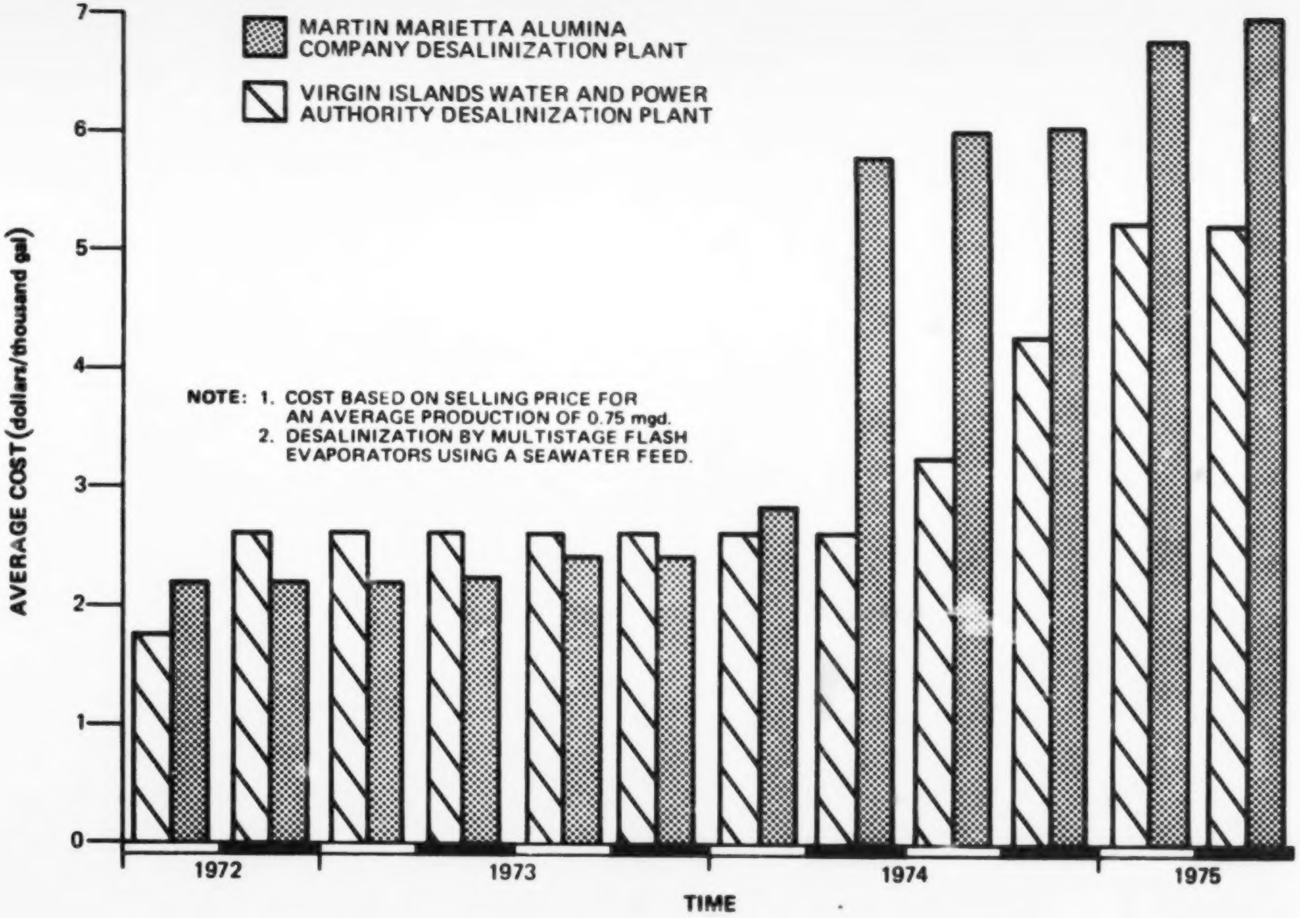

Figure 4. The cost of desalinized water purchased during the period 1972 to 1975.

The potential source of this reusable water, public wastewater flows, receives only primary or no treatment at all before being discharged into the ocean. However, in accordance with the current implementation of federal environmental legislation, it may soon be necessary to provide secondary treatment to all wastes discharged from the island. All of these steps require progressively higher quality effluent, and very little extra processing is required to adapt these effluents to various water reuse programs on the island. Among these programs would be reuse for agricultural irrigation, pisciculture, groundwater augmentation, fire control, prevention of saltwater intrusion, and various industrial purposes.

The idea of wastewater reclamation is not new, the inadvertent reuse of wastewater being rather widespread throughout the United States and the rest of the world. It is a major factor necessitating the treatment of water before distribution to the public. Koenig (1966) in a study of 155 communities in the United States served by surface water found that, including industrial wastewaters, the median reuse factor was about 50 percent. Throughout the world there are areas where deliberate reuse of wastewater is being practiced. These are predominantly in the arid regions where the cost of procuring new water exceeds that of processing wastewater for reuse. Localities in California, Texas, Israel, and South Africa are utilizing wastewater reclamation plants for various purposes.

OUTLINE OF THE WASTEWATER RECLAMATION PROJECT

Project Description

The concept of wastewater reclamation and its subsequent reuse for groundwater recharge on St. Croix has been studied and suggested by the U.S. Geological Survey (Robison, 1972; Jordan, 1973) and engineering consultants (Engineering-Science Inc., 1968). This report covers a study entitled "Wastewater Reclamation Project on St. Croix, U.S. Virgin Islands," which was sponsored by the U.S. Environmental Protection Agency (EPA) and the Virgin Islands Government, Division of Natural Resources Management. In this project a portion of the flow normally discharged to the sea from the island's new primary treatment plant at Bethlehem Middle Works was used for reclamation purposes. The flow was diverted and processed in an advanced wastewater treatment plant (AWWTP) adjacent to the primary plant. Processing was by biological and physiochemical means and produced a treated wastewater which was conveyed by a force main to recharge areas located about 1-1/4 miles (2 km) away. Here it was stored in a holding tank and introduced into the groundwater aquifers by various methods. This was for the purpose of improving the yield of wells in the area and assisting in preventing further seawater intrusion which threatens Fair Plains, one of the government's major well fields on the island.

The project was handled for the government by the consulting engineering firm of Black, Crow and Eidsness, Inc., of Gainesville, Florida. Project personnel worked on the island continuously from April, 1971, to October, 1975, studying the problem, supervising the construction, operating all of the facilities involved, and evaluating the results. Early in the project the recharge sites were located and a study area of about 8 square miles (23 km) was defined, which included the drainage basins where the recharge activities would take place. Wells and surface water throughout this study area were monitored for 2-1/2 years in order to clarify the hydrological characteristics of the region and to establish baseline data for the project before recharging began. The study area is outlined in Figures 2 and 5. The most important portion of the region is shown in detail in Figure 6.

Project Objective

The overall objective of this project was to determine the feasibility of increasing the freshwater reserves on St. Croix by the use of wastewater reclamation. This consisted of the artificial recharge of the groundwater on the island using tertiary-treated wastewater effluent. The project entailed not only the operation of the treatment and recharge facilities but the study of the wastewater collection system; the geohydrological character of the recharge area and the subsequent water distribution; evaluation of the effects on the groundwater regime; and the costs associated with the production of fresh water in this manner.

Project Phases

The project was divided into four phases: initiation, investigation, operation, and evaluation. A diagrammatical outline of these phases and their scheduling during the project is shown in Figure 7.

Phase 1 - Initiation. This included the discussions and efforts made in formulating a proposal that outlined the steps of the investigation and proposed a budget to match these plans. During this time the grant application and approval were obtained and a contractual agreement between the parties involved was defined and finalized. This phase ended in March, 1971, with the assignment of a full-time engineer to the project who began field work on St. Croix the following month.

Phase 2 - Investigation, Design, and Construction. This phase covered the investigation of the conditions that affect the recharging operation and included the selection of the sites for recharging and the area to be monitored during the project. Studies were made of the hydrology, geology, soils, land use, groundwater, and surface water, in the study area. A monitoring program was begun to establish baseline data on water quality and quantity. An advanced wastewater

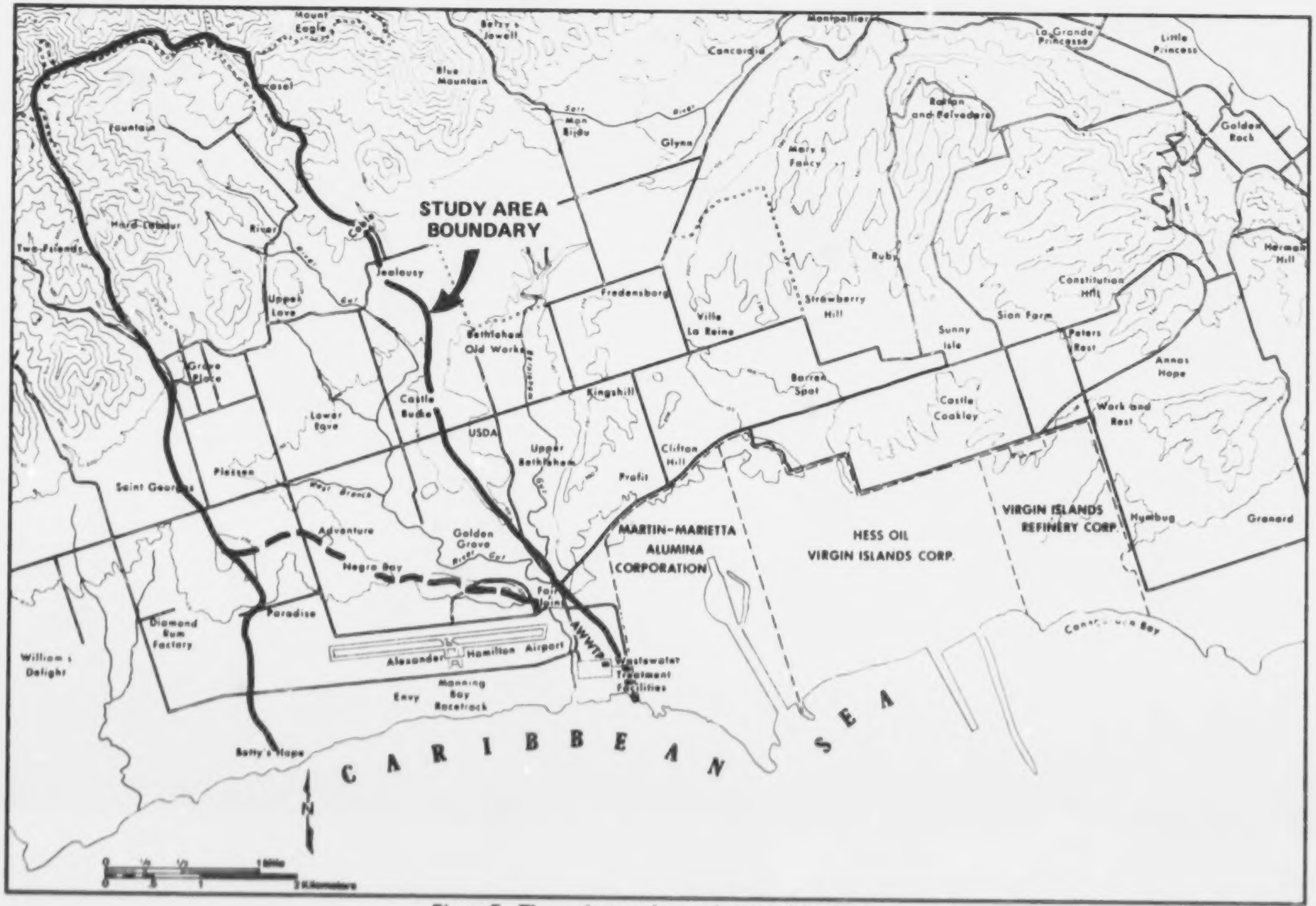
Mount Eagle
Betsy's Jewell
Blue Mountain
Montpellier
Concordia
La Grande Princesse
Little Princess
Golden Rock
Hermon Hill
Rattan and Belvedere
Mary's Fancy
Glynn
Mon Bijou
Salt River
Fountain
Hard Labour
River
Two Friends
STUDY AREA BOUNDARY
Jealousy
Upper Love
Grove Place
Bethlehem Old Works
Fredensborg
Ville La Reine
Strawberry Hill
Ruby
Sunny Isle
Sion Farm
Constitution Hill
Peters Rest
Annas Hope
Work and Rest
Castle Burke
Lower Love
Kingshill
USDA
Upper Bethlehem
Profit
Clifton Hill
Barren Spot
Castle Coakley
Plessen
Saint Georges
West Branch
Adventure
Golden Grove
River Gut
Negro Bay
Fair Plain
Paradise
Diamond Rum Factory
William's Delight
Alexander Hamilton Airport
AWWTP
Wastewater Treatment Facilities
Envy
Manning Bay
Racetrack
Betty's Hope
MARTIN-MARIETTA ALUMINA CORPORATION
HESS OIL VIRGIN ISLANDS CORP.
VIRGIN ISLANDS REFINERY CORP.
Humbug
Granard
Bay
CARIBBEAN SEA
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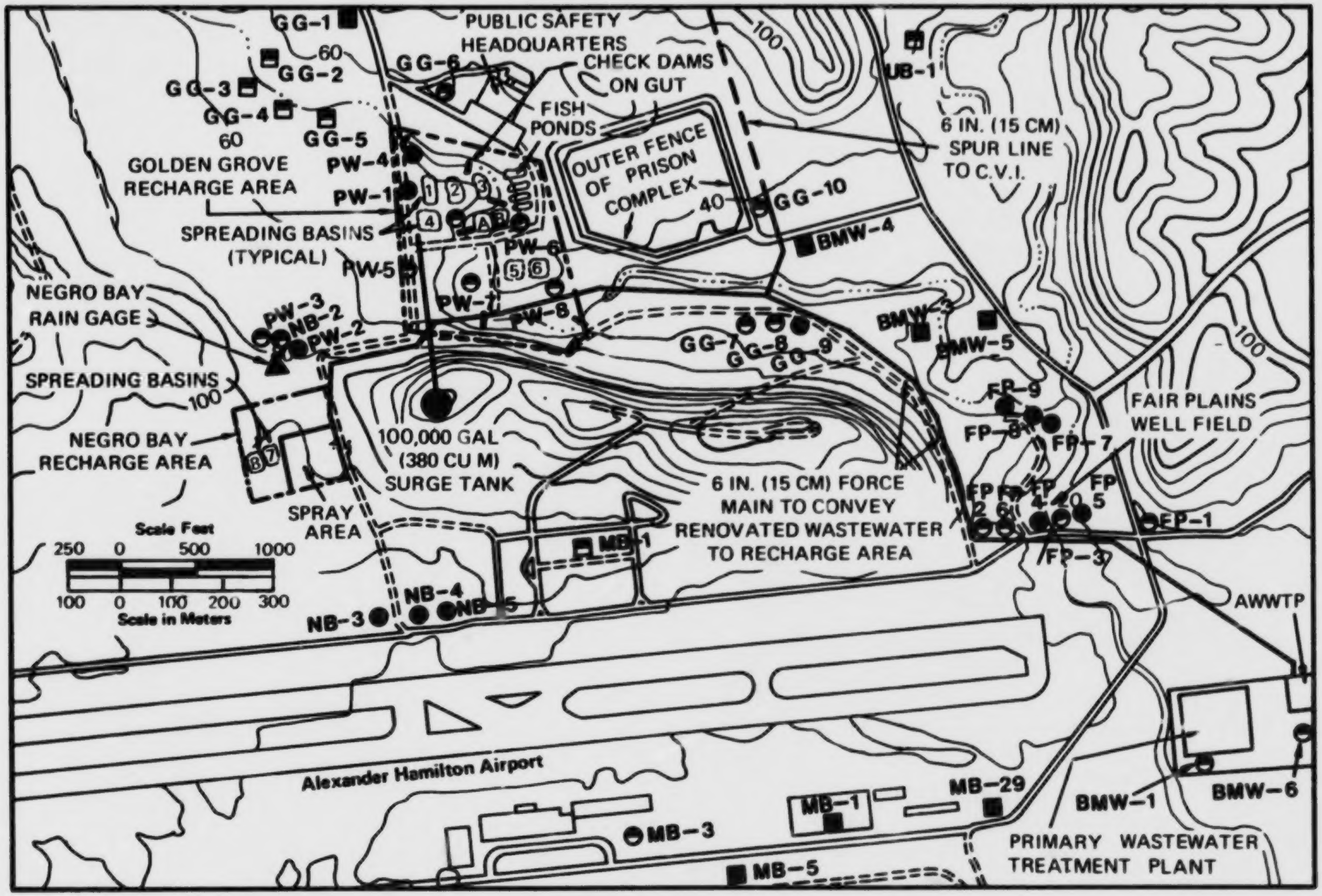
Figure 5. The project study area in central St. Croix.


GG-1
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GG-2
GG-3
GG-4
60
GG-5
GG-6
PUBLIC SAFETY HEADQUARTERS
CHECK DAMS ON GUT
FISH PONDS
OUTER FENCE OF PRISON COMPLEX
40
GG-10
BMW-4
UB-1
100
6 IN. (15 CM) SPUR LINE TO C.V.I.
GOLDEN GROVE RECHARGE AREA
PW-4
PW-1
1
2
3
4
A
B
SPREADING BASINS (TYPICAL)
PW-5
PW-6
5
6
PW-7
PW-8
NEGRO BAY RAIN GAGE
PW-3
NB-2
PW-2
SPREADING BASINS
100
NEGRO BAY RECHARGE AREA
8
7
SPRAY AREA
100,000 GAL (380 CU M) SURGE TANK
GG-7
GG-8
GG-9
BMW-3
BMW-5
FP-9
FP-8
FP-7
FAIR PLAINS WELL FIELD
100
6 IN. (15 CM) FORCE MAIN TO CONVEY RENOVATED WASTEWATER TO RECHARGE AREA
FP 2
FP 6
FP 4
40
FP 5
FP-1
FP-3
MB-1
Scale Feet
250
0
500
1000
100
0
100
200
300
Scale in Meters
NB-3
NB-4
NB-5
AWWTP
Alexander Hamilton Airport
MB-1
MB-29
MB-3
MB-5
BMW-1
BMW-6
PRIMARY WASTEWATER TREATMENT PLANT

Figure 6. The Golden Grove and Negro Bay area in central St. Croix.

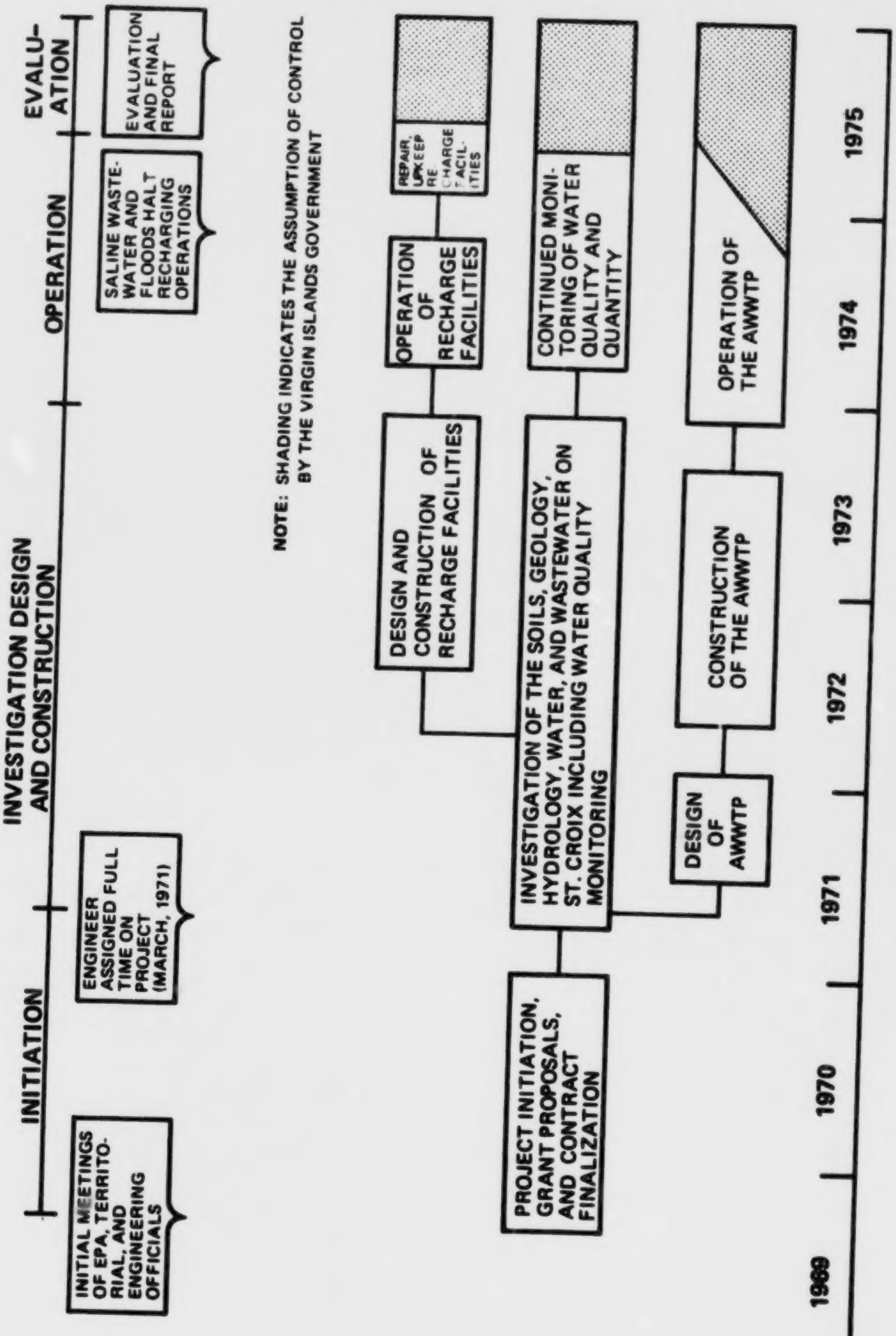

INITIATION
INVESTIGATION DESIGN AND CONSTRUCTION
OPERATION
EVALUATION
INITIAL MEETINGS OF EPA, TERRITORIAL, AND ENGINEERING OFFICIALS
ENGINEER ASSIGNED FULL TIME ON PROJECT (MARCH, 1971)
SALINE WASTEWATER AND FLOODS HALT RECHARGING OPERATIONS
EVALUATION AND FINAL REPORT
NOTE: SHADING INDICATES THE ASSUMPTION OF CONTROL BY THE VIRGIN ISLANDS GOVERNMENT
DESIGN AND CONSTRUCTION OF RECHARGE FACILITIES
OPERATION OF RECHARGE FACILITIES
REPAIR, UPKEEP RECHARGE FACILITIES
PROJECT INITIATION, GRANT PROPOSALS, AND CONTRACT FINALIZATION
INVESTIGATION OF THE SOILS, GEOLOGY, HYDROLOGY, WATER, AND WASTEWATER ON ST. CROIX INCLUDING WATER QUALITY MONITORING
CONTINUED MONITORING OF WATER QUALITY AND QUANTITY
DESIGN OF AWWTP
CONSTRUCTION OF THE AWWTP
OPERATION OF THE AWWTP
1969
1970
1971
1972
1973
1974
1975

Figure 7. Schedule of the phases of the wastewater reclamation project.

treatment plant (AWWTP), force main, holding tank, and recharge facilities were designed and constructed. All facilities were tested for operation. This phase was completed in January, 1974.

Phase 3 - Operation. Phase 3 began in February, 1974, and consisted of operating the plant and recharge facilities. Improvements and modifications were made to the AWWTP and recharge facilities as required during the operational phase. Recharging operations continued until October, 1974, when they were curtailed due to the high total dissolved solids (TDS) in the incoming wastewater. The high TDS was caused by the saltwater flushing system employed in the town of Frederiksted which was connected to the central wastewater interceptor system during that month. In November, 1974, the primary plant and wastewater collection network were rendered inoperative by heavy rains and flooding. Also damaged were the recharge facilities in Estate Golden Grove. Repairs to all facilities were completed by May, 1975. However, further recharge operations were restricted by the high TDS in the collected wastewater due to the use of salt water for flushing in the town of Frederiksted. The operational phase of the project ended in May, 1975, with the complete transfer of the project facilities to the Virgin Islands Government, Division of Natural Resources Management.

Phase 4 - Evaluation. The data gathered throughout the project were evaluated to determine the actual feasibility of the project, both on a technical and economical basis. This final report contains the results of the evaluation and contains recommendations for further development of the wastewater reclamation project. Phase 4 was completed in November, 1975, with the completion of this report.

SECTION II

SUMMARY

The wastewater reclamation project on St. Croix has demonstrated that it is possible to economically augment the island's freshwater reserves through the use of reclaimed wastewater for the artificial recharge of groundwater. The most successful method of recharge has been with the use of spreading basins in Estate Golden Grove.

The project has spanned close to 5-1/2 years from its initiation to the publication of this final report. It has resulted in the construction and operation of an advanced wastewater treatment plant and recharge facilities which can process up to 0.5 mgd (1,892 cu m/day). Investigation of the geology, hydrology, and groundwater movement in the area and the compilation of considerable data on treatment plant operations, recharge activity, well water quality, and groundwater quantity has been completed.

After numerous delays in the construction of the treatment plant, recharging operations began in February, 1974. During the subsequent 8 months various minor problems in the system were resolved and plant production steadily increased until in October, 1974, it was possible to recharge an average of 1 mil gal/wk (3,785 cu m/wk). The restriction at that point was caused by a lack of treated wastewater effluent, rather than the capacity of the recharge areas.

Of the two recharge sites utilized it was possible to eliminate one and focus all attention on the most feasible site at Estate Golden Grove. At the recharge rate used in Golden Grove, no significant adverse effects were observed among the parameters examined in the groundwater extracted downstream of the project. There was, however, evidence of a notable increase in available groundwater in the vicinity of the recharge activities.

The major problems experienced during the project's operational phase were:

The lack of sufficient wastewater for treatment and subsequent recharge.

The mechanical failure of equipment associated with the treatment process.

The transfer, to the central treatment plant, of wastewater containing a high percentage of seawater.

This last problem, followed immediately by a record flood on the island, caused the premature termination of the recharge activities in October, 1974. Although the flood damage has been repaired, it is not expected that the saltwater problem will be resolved until the latter part of 1975. At that time it will be possible to resume the artificial recharge activities.

Using the present facilities for treatment and recharging it is estimated that recoverable groundwater could be increased by at least 0.35 mgd (1,351 cu m/day) at the recovered water cost of about $2.15/thousand gal ($0.56/cu m).

Although this is considerably higher than the $0.30/thousand gal ($0.08/cu m) estimated for recovering the limited amount of groundwater, it is much cheaper than the cost of $5.16/thousand gal ($1.36/cu m) for water produced by the government's desalinization plant on the island and additionally it will provide a dependable source of fresh water for St. Croix.

In addition to the work on artificial recharge, the project personnel worked with other public and private entities on the island to foster the use of reclaimed wastewater for other purposes. This proved to be successful and broadened community support and participation in the idea of water reuse. Among the other reuse projects that are being carried out on St. Croix are agricultural irrigation, pisciculture, and the raising of freshwater clams.

Continuing research on the project will be carried out by the territory's Water Resources Research Center located at the College of the Virgin Islands in St. Thomas.

SECTION III

CONCLUSIONS

It is economically feasible to use reclaimed wastewater to artificially recharge the groundwater on St. Croix. However, it can only be accomplished successfully at carefully selected areas on the island. A site in the alluvial valley at Estate Golden Grove was demonstrated to be highly suitable for recharge by the use of spreading basins.

With the AWWTP operating at design capacity of 0.5 mgd (1,892 cu m/day) and allowing for down time and losses in groundwater recovery, it will be possible to recover groundwater for a cost of about $2.15/thousand gal ($0.57/cu m). With expansion of the existing plant and recharge areas to a capacity of 1 mgd (3,785 cu m/day) the cost can be reduced to about $1.64/thousand gal ($0.43/cu m).

It is not economical to artificially recharge and recover any of the subsequent groundwater from the marl formation in the recharge area in Estate Negro Bay on St. Croix. Infiltration and percolation rates were too low and evapotranspiration rates were too high to warrant further efforts in this type of soil structure.

With the existing AWWTP it is possible to treat the incoming wastewater, as it was constituted during the 8 months of recharge activity, so that with normal operation the effluent will have a turbidity of less than 3 Formazin turbidity units (FTUs) and a free chlorine residual of over 3 mg/l, after a 30-minute contact time (see Section VIII).

The use of an effluent low in organics and turbidity with a free chlorine residual for artificial recharge in the recharge basins in Estate Golden Grove will permit the operation of the basins with a minimum of odor or algae problems and a high rate of infiltration into the soil. The average sustained rate of infiltration experienced in the Golden Grove basins was about 14 gpd/sq ft (0.57 cu m/day/sq m) on a wet cycle basis.

The recharging activities which took place in Golden Grove and Negro Bay, during the 8-month period of project operations in 1974, did not significantly affect the water quality of any pumped well in the area on the basis of the parameters examined (see Section VII).

The use of seawater for flushing purposes must be terminated in areas where the wastewater is to be processed for reuse.

SECTION IV

RECOMMENDATIONS

Continue the Project

The reclamation of wastewater for artificial groundwater recharge should be continued on St. Croix. It has proved to be an economically feasible enterprise and should be a benefit to the island not only for groundwater augmentation but other uses as well.

Strengthen the Organization

The entire reclamation project is of sufficient importance and complexity that it requires careful organization and staffing to ensure its future success. If the operation continues within the Division of Natural Resources Management, it should be organized with one person having the responsibility for operations, monitoring, distribution, and coordination with other agencies. This person should be an engineer with experience and/or training in both the fields of water supply and wastewater treatment. He should probably hold the title of Assistant Director. There should continue to be a separate superintendent for the AWWTP since this, in itself, is a full-time job.

The AWWTP and recharge facility must be adequately manned. It presently is understaffed and will not be able to sustain full production for very long without additional staff.

Coordination with other departments and individuals concerned with the reuse of water is vital to the efficient utilization of this resource. The program of expansion and promotion of water reuse for beneficial purposes must continue to stress the multiuse concept of the project.

Coordinate Future Planning

The concept of the reuse of water must be incorporated into all aspects of planning for water supply and wastewater collection on St. Croix. Although it may not be advantageous to recycle all of the water on the island, all new water and wastewater installations and changes, both public and private, must be reviewed as to their effect on the reclamation project. A master plan for water management on St. Croix, which will be published about March, 1976, will aid in this evaluation process.

Control Saltwater Usage

The use of seawater as a source of fire and flushing water must be carefully evaluated since its use is not compatible with the reclamation of wastewater at a reasonable cost. It must be remembered, though, that salt water is a very inexpensive source of water. The complexity and expense of attempting to eliminate all saltwater discharges to the wastewater collection system on the island may not be commensurate with the benefits derived from a 100 percent reuse capability.

At the present time, it is recommended that the saltwater usage in Frederiksted be eliminated by the direct use of fresh water in the saltwater system. This will require about 0.08 mgd (300 cu m/day) of fresh water. This will permit the use in the AWWTP of at least 0.5 mgd (1,892 cu m/day) of low chloride wastewater for reclamation purposes. The additional fresh water produced through artificial recharge and recovery can be returned to the system to make up the flushing water. This will permit the reclamation project to operate until about June, 1977, when the wastewater interceptor system is completed to Christiansted and the wastewater containing salt water from Christiansted will be delivered to the central treatment plant on the south shore. Christiansted uses an estimated 0.6 mgd (2,271 cu m/day) of seawater for flushing purposes, which is over 7 times the amount used in Frederiksted and hence difficult to replace with fresh water.

If, by approximately June, 1976, plans for the elimination of all the salt water in the Christiansted area have not been finalized and agreed to in plan and principle by the Public Works Department, V.I. Housing Authority, and the owners of the major hotels, condominiums, and restaurants using salt water, then it is doubtful that the wastewater coming from the area can be used for reclamation purposes and without further modifications the project would probably be shut down again in 1977. The unilateral prohibition of saltwater usage in the area without an immediately available, cheap alternative would probably create an extremely negative reaction against the concept of water reuse.

Split the Wastewater Flow at the Primary Plant

If the salt water cannot be eliminated from the Christiansted area, then it is recommended that a new pumping station be built adjacent to the collection structure at the primary treatment plant. This pumping station would pick up a percentage of the wastewater entering the structure from the central and western portions of the island before it is contaminated by the salty wastewater from Christiansted. The pumping station would then transfer the wastewater directly to the AWWTP with provisions for screening and degritting enroute or via one of the primary settling tanks. In the latter case, the primary facility would need to be altered to permit the splitting of flows within the plant so that the high and low TDS wastewaters could be treated separately.

With this plan, reclamation efforts could be continued and expanded to the capacity of the influent available. If successful extended operation at that level indicated that the usage could be expanded to efficiently utilize most of the wastewater from Christiansted; then careful, coordinated plans could be made and carried out to initiate the needed changes to smoothly incorporate this additional supply into the water reuse system.

Promulgate Regulations Concerning Reuse

As soon as practicable, the proper territorial agency or agencies should promulgate regulations specifically governing the use of reclaimed wastewater for groundwater recharge, agricultural irrigation, and any other activity involving water reuse. These would provide guidelines for the planners and operators associated with the facilities. As the EPA has gained additional knowledge and experience in the field of water reuse since it initiated this project in 1969, it is advised that the EPA be consulted for guidance and assistance in reviewing the regulatory and monitoring portions of the project in the future.

Monitoring Future Operations

Monitoring in the study area should be continued. This should include chemical and biological analysis and the gaging of water levels in selected wells. A thorough review of the type of analyses run should be made and modified where appropriate. It is suggested that BOD and COD measurements of the wells be suspended and that, at a minimum, all the tests covered in the proposed new EPA drinking water standards (Environmental Protection Agency, 1975) be instituted.

Disinfection of Recovered Water

All water extracted from the Golden Grove well field in association with the recharge operation should be monitored and thoroughly disinfected, as a safety precaution, before distribution. The Fair Plains collection tank and pumping station should be the focal point for monitoring, disinfection, and distribution of this water. The two direct taps onto the force main connecting the Golden Grove well field to the Fair Plains tank should be either disconnected or altered in a way that will assure proper disinfection of any water used. These two taps feed the adult correctional facility and the Public Safety Headquarters.

The disinfection operation at Fair Plains must be carefully monitored to ensure that it is being carried out properly at all times. Consideration needs to be given to the installation of a gas chlorinator instead of the current dry chemical chlorinator system.

Prohibit Industrial Wastes

Industrial wastes should not be added to the wastewater ultimately used for reclamation purposes unless they have been carefully analyzed and evaluated. This is to ensure that no harmful exotic substances are introduced into the reuse system.

Monitor Coagulants' Effectiveness

The effectiveness of using aluminum sulfate as a coagulant and filter aid should be continually monitored as the project continues. The projected changes in the major water source in the western portion of the island from groundwater to distilled water may have a detrimental effect on the alum reaction. Other chemicals, including polyelectrolytes, may be required in the future. Any chemicals employed should be approved by the EPA for water treatment usage.

Improve Groundwater Recovery

The existing recharge facilities were not intended to maximize the recovery of recharged water. Additional groundwater extraction facilities should be constructed in Estate Golden Grove to facilitate this.

The emphasis should be on the removal of the groundwater from the upper aquifer which is the one being artificially recharged. Figure 8 is a sketch of the Golden Grove recharge area and shows the sequence of well field development that should take place. Initially, at least the first six recovery wells should be installed. These wells are located so as to permit rapid removal of water from under the scattered recharge basins. The additional wells are planned to coincide with the expansion of the recharge basins as shown in Figure 9. A feature of this development should be a horizontal collection system constructed along the northwest property boundary between wells RW-12, RW-6, PW-1, RW-1, and PW-4. At this point the upper aquifer is close enough to the surface to permit excavation and installation of the necessary collectors. A sketch of this system is shown in Figure 10. As information is gained through the construction and pumping of the wells, the proposed locations of the additional wells and basins should be continually reevaluated.

All extraction facilities, wells, or collectors shown have been located so as to maintain the minimum 50 ft (15 m) horizontal distance between the wells and the recharge facilities as required by the V.I. Division of Natural Resources Management (Stolz, 1975). This placement affords a high degree of hydraulic efficiency for the removal of recharged water from below the basins, but these wells should be carefully monitored to ensure that the desired groundwater quality can be maintained.

Expand the Recharge Area in Golden Grove

Expansion of the spreading basins should take place as shown in Figure 9. The area suitable for surface methods of recharging is rather limited in size and expansion in Estate Golden Grove beyond the areas shown will probably be uneconomical.

Improve the Performance of the AWWTP

The performance and production of the AWWTP would significantly improve if a steady flow rate to the plant could be maintained. This can be accomplished by relocating the influent pumps from the present wet well to the primary clarifier along with the installation of a new, larger diameter pipeline. This is described in detail in the section on project facilities under the subheading Plant Expansion. The majority of the work can be accomplished by local government personnel and the materials required would cost less than $10,000. It is urged that this change be instituted as soon as possible.

Consider AWWTP Expansion

The present plant and installed equipment have the capability to permit considerable expansion of plant capacity with a relatively low amount of capital investment. However expansion should only be carried out if there is full utilization of the present production and a reasonable prospect for the use of additional reclaimed water. Plant expansion is discussed in further detail in the section, Description of the Project Facilities.

Expand Local Research

Research projects on water reuse as they apply to conditions within the territory should be encouraged. The newly established Water Resources Center at the College of the Virgin Islands should take a leading role in directing and funding this research. Some of the following are suggested topics for research.

> The long- and short-term effects on the various local soils as the result of using reclaimed wastewater for recharge and irrigation purposes.
>
> The fate of nutrients, organics, and microorganisms in reclaimed wastewater as it moves through the various types of local soils.
>
> Viral studies in the reclaimed wastewater and recovered groundwater.

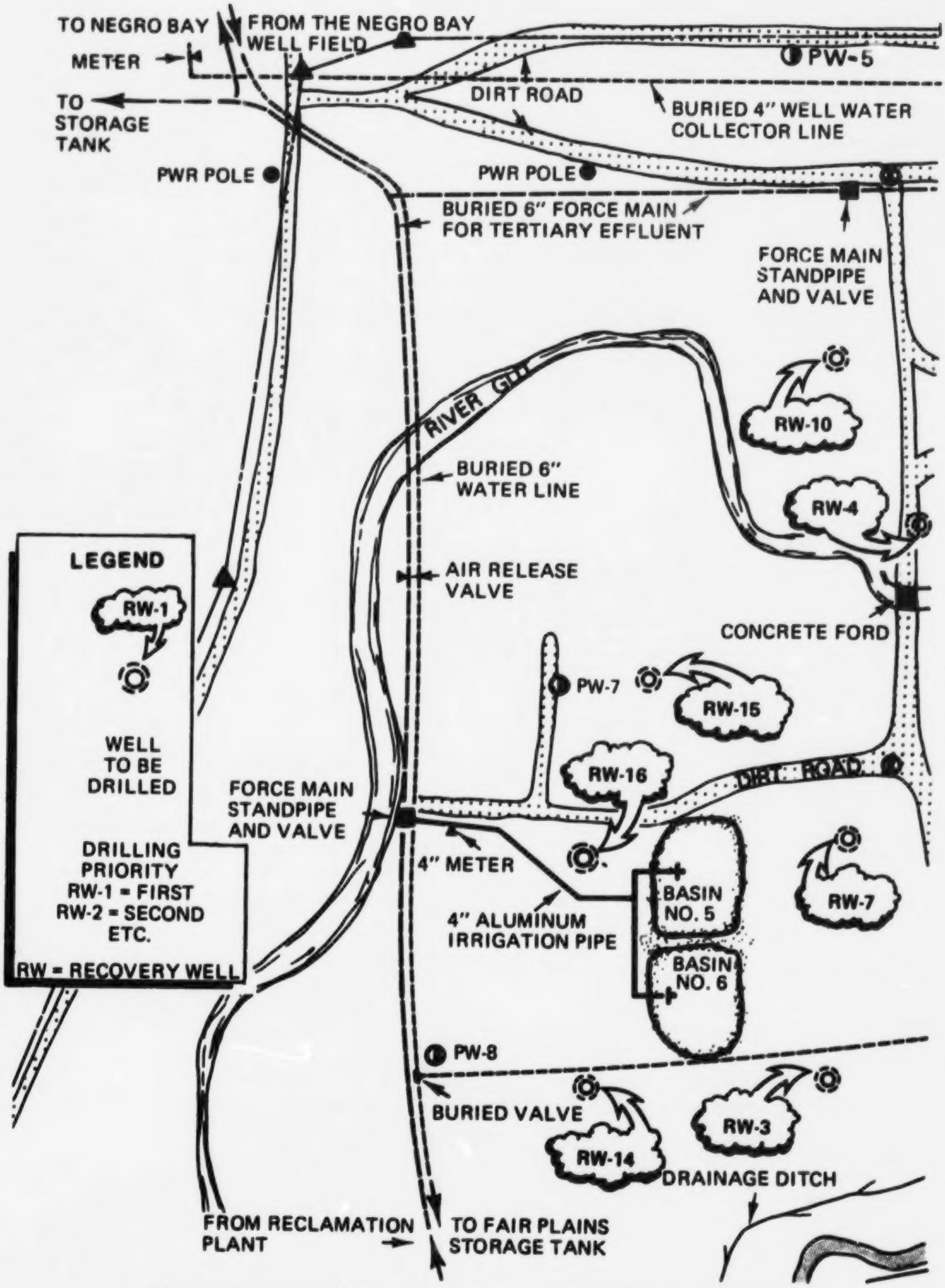

TO NEGRO BAY
FROM THE NEGRO BAY WELL FIELD
METER
PW-5
TO STORAGE TANK
DIRT ROAD
BURIED 4" WELL WATER COLLECTOR LINE
PWR POLE
PWR POLE
BURIED 6" FORCE MAIN FOR TERTIARY EFFLUENT
FORCE MAIN STANDPIPE AND VALVE
RIVER GUT
RW-10
BURIED 6" WATER LINE
RW-4
LEGEND
RW-1
WELL TO BE DRILLED
DRILLING PRIORITY
RW-1 = FIRST
RW-2 = SECOND
ETC.
RW = RECOVERY WELL
AIR RELEASE VALVE
CONCRETE FORD
PW-7
RW-15
RW-16
DIRT ROAD
FORCE MAIN STANDPIPE AND VALVE
4" METER
RW-7
BASIN NO. 5
4" ALUMINUM IRRIGATION PIPE
BASIN NO. 6
PW-8
BURIED VALVE
RW-3
RW-14
DRAINAGE DITCH
FROM RECLAMATION PLANT
TO FAIR PLAINS STORAGE TANK

Figure 8. Future well field development in the Golden Grove recharge area.

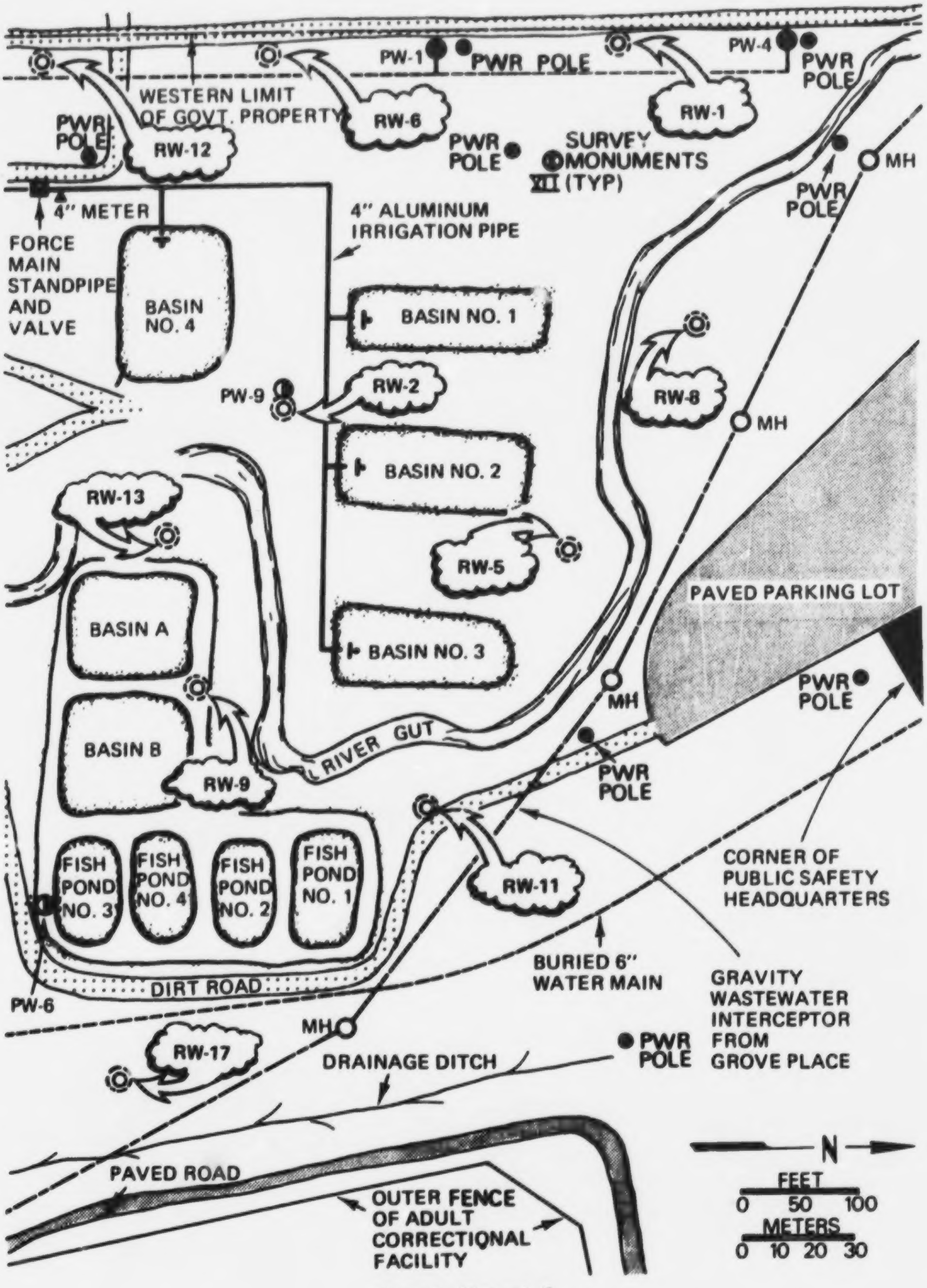

PW-1
PWR POLE
PW-4
PWR POLE
WESTERN LIMIT OF GOVT. PROPERTY
RW-6
RW-1
PWR POLE
RW-12
PWR POLE
SURVEY MONUMENTS
XII (TYP)
PWR POLE
MH
4" METER
4" ALUMINUM IRRIGATION PIPE
PWR POLE
FORCE MAIN STANDPIPE AND VALVE
BASIN NO. 4
BASIN NO. 1
PW-9
RW-2
RW-8
MH
BASIN NO. 2
RW-13
RW-5
PAVED PARKING LOT
BASIN A
BASIN NO. 3
MH
PWR POLE
BASIN B
RIVER GUT
RW-9
PWR POLE
FISH POND NO. 3
FISH POND NO. 4
FISH POND NO. 2
FISH POND NO. 1
RW-11
CORNER OF PUBLIC SAFETY HEADQUARTERS
DIRT ROAD
BURIED 6" WATER MAIN
GRAVITY WASTEWATER INTERCEPTOR FROM GROVE PLACE
PW-6
MH
RW-17
PWR POLE
DRAINAGE DITCH
N
PAVED ROAD
FEET
0 50 100
METERS
0 10 20 30
OUTER FENCE OF ADULT CORRECTIONAL FACILITY

Figure 8. (Extended)

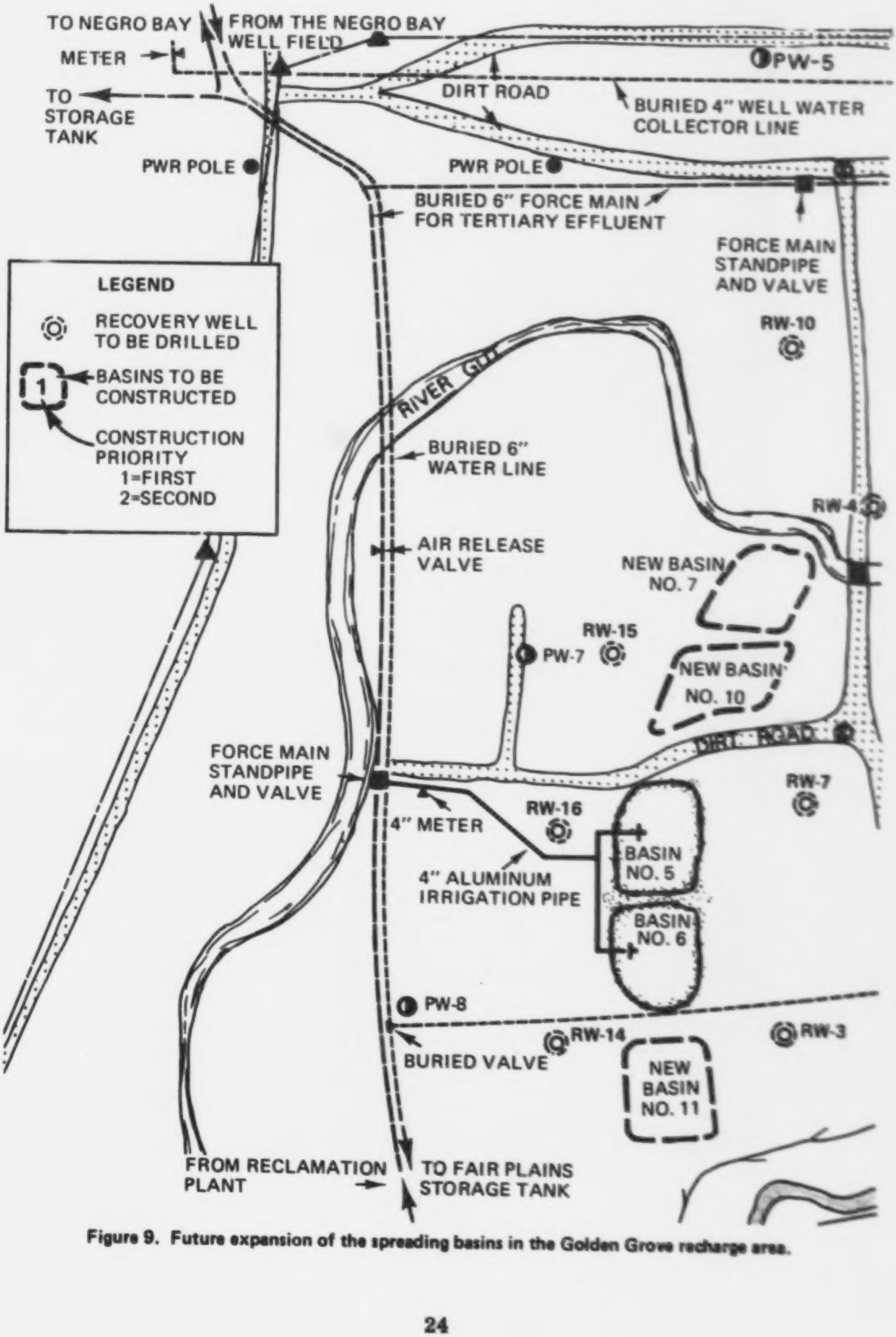

TO NEGRO BAY
FROM THE NEGRO BAY WELL FIELD
METER
PW-5
TO STORAGE TANK
DIRT ROAD
BURIED 4" WELL WATER COLLECTOR LINE
PWR POLE
PWR POLE
BURIED 6" FORCE MAIN FOR TERTIARY EFFLUENT
FORCE MAIN STANDPIPE AND VALVE
LEGEND
RECOVERY WELL TO BE DRILLED
1
BASINS TO BE CONSTRUCTED
CONSTRUCTION PRIORITY
1=FIRST
2=SECOND
RW-10
RIVER GUT
BURIED 6" WATER LINE
RW-4
AIR RELEASE VALVE
NEW BASIN NO. 7
RW-15
PW-7
NEW BASIN NO. 10
DIRT ROAD
FORCE MAIN STANDPIPE AND VALVE
RW-7
RW-16
4" METER
BASIN NO. 5
4" ALUMINUM IRRIGATION PIPE
BASIN NO. 6
PW-8
RW-14
RW-3
BURIED VALVE
NEW BASIN NO. 11
FROM RECLAMATION PLANT
TO FAIR PLAINS STORAGE TANK

Figure 9. Future expansion of the spreading basins in the Golden Grove recharge area.

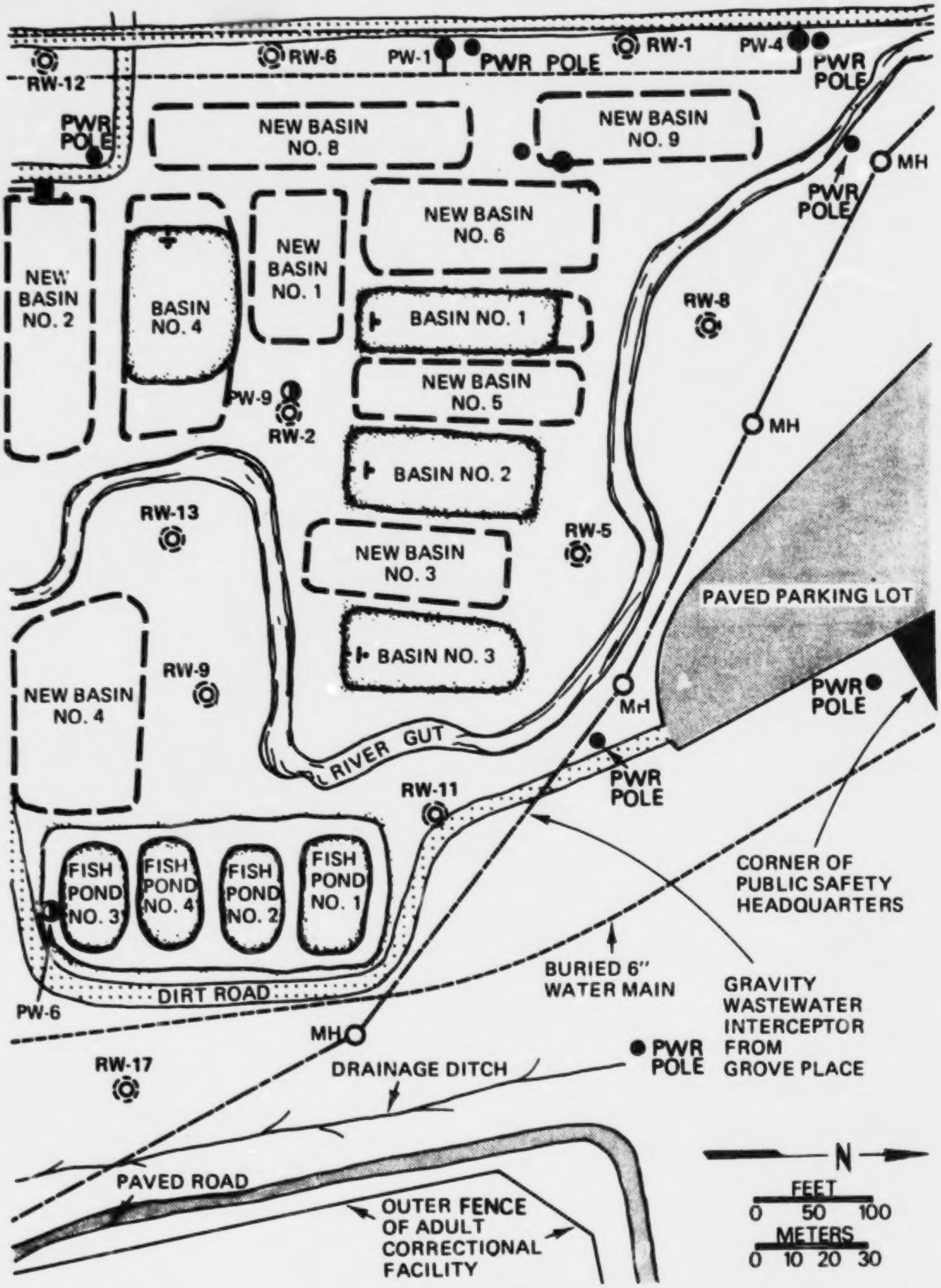
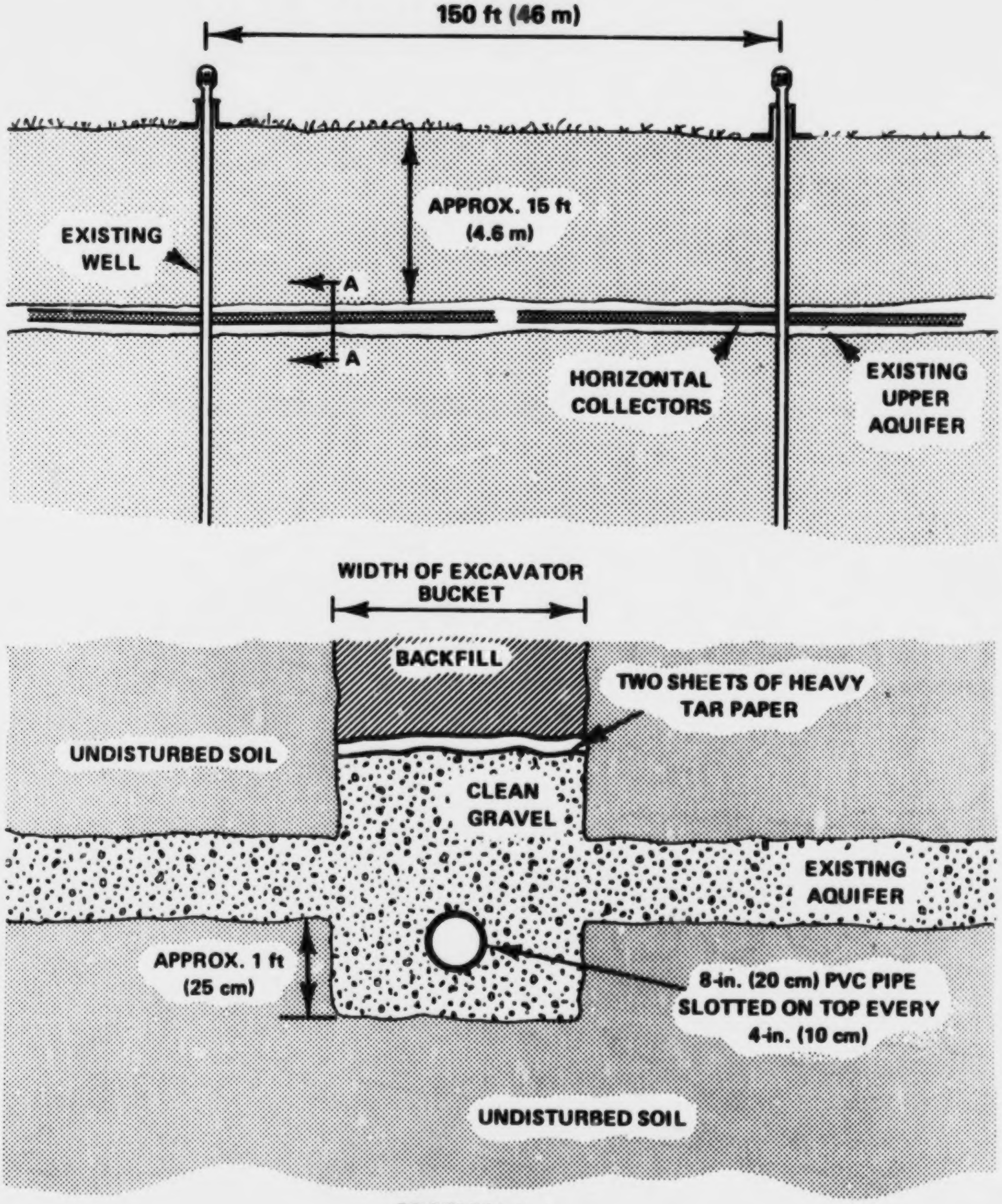

RW-12
RW-6
PW-1
PWR POLE
RW-1
PW-4
PWR POLE
PWR POLE
NEW BASIN NO. 8
NEW BASIN NO. 9
PWR POLE
MH
NEW BASIN NO. 2
BASIN NO. 4
NEW BASIN NO. 1
NEW BASIN NO. 6
BASIN NO. 1
RW-8
NEW BASIN NO. 5
PW-9
RW-2
MH
BASIN NO. 2
RW-13
RW-5
NEW BASIN NO. 3
PAVED PARKING LOT
BASIN NO. 3
RW-9
NEW BASIN NO. 4
MH
PWR POLE
RIVER GUT
PWR POLE
RW-11
FISH POND NO. 3
FISH POND NO. 4
FISH POND NO. 2
FISH POND NO. 1
CORNER OF PUBLIC SAFETY HEADQUARTERS
BURIED 6" WATER MAIN
GRAVITY WASTEWATER INTERCEPTOR FROM GROVE PLACE
DIRT ROAD
PW-6
MH
RW-17
DRAINAGE DITCH
PWR POLE
N
PAVED ROAD
OUTER FENCE OF ADULT CORRECTIONAL FACILITY
FEET
0 50 100
METERS
0 10 20 30

Figure 9. (Extended)


150 ft (46 m)
APPROX. 15 ft (4.6 m)
EXISTING WELL
A
A
HORIZONTAL COLLECTORS
EXISTING UPPER AQUIFER
WIDTH OF EXCAVATOR BUCKET
BACKFILL
TWO SHEETS OF HEAVY TAR PAPER
UNDISTURBED SOIL
CLEAN GRAVEL
EXISTING AQUIFER
APPROX. 1 ft (25 cm)
8-in. (20 cm) PVC PIPE SLOTTED ON TOP EVERY 4-in. (10 cm)
UNDISTURBED SOIL

SECTION A-A

Figure 10. Proposed horizontal well.

The uptake of nutrients, heavy metals, microorganisms, etc., in local plant materials as a result of the use of reclaimed wastewater for irrigation purposes.

Quantification of the loss of groundwater by the transpiration of subtropical vegetation in the territory.

Evaluation and revisions, where necessary, of regulations and guidelines governing the use of reclaimed wastewater.

A review of the areas of research needed in the field of water reuse has been made in the paper, "Research required to establish confidence in the potable reuse of wastewater," (English et al., 1975). This paper provides additional topics for investigation.

Reduce Costs

The best method to reduce costs would be to combine the staffs of the adjacent primary treatment plant with that of the AWWTP. The present arrangement where each plant has a separate staff is an inefficient use of manpower and equipment. Combining them under one government agency with one head would reduce overall labor costs and permit coordinated operation to the benefit of the wastewater reclamation project.

SECTION V

PRELIMINARY INVESTIGATIONS OF THE RECHARGE AND STUDY AREA

SELECTION OF THE RECHARGE AND STUDY AREA

The key decision in the project was the selection of the recharge area. If an unsuitable site had been selected and developed, then the remainder of the effort on the project would have been largely wasted. Therefore the preliminary investigations centered around the selection of a suitable site and the definition of its hydrogeological features.

In the selection of the areas which were used for recharging, there were two major constraints involved. The first was financial in that the budget for the project only provided sufficient funds for up to 2 miles (3.2 km) of force main. Thus, the maximum distance of the recharge area from the advanced wastewater treatment plant was predetermined.

The second major constraint was that the basic decisions as to the pattern of wastewater interceptors and the location of the central primary treatment plant were made by others before this project was begun. Since the influent for the advanced wastewater treatment plant (AWWTP) would come directly from this primary plant, the location of that plant determined the site of the advanced wastewater treatment plant.

The budget for development of the recharge areas was based upon the understanding that the land utilized must be obtained at little or no cost. At the time when the original proposal was outlined in 1969, local officials had indicated that there would be little problem in using land at Estate Barren Spot in central St. Croix. This probably seemed natural at the time as the area then consisted of abandoned fields of sugarcane. The recharge areas were proposed for a location which was on alluvial soil and in the same hydrological basin as one of the larger public well fields on the island.

However, between 1969 and the start of the project in 1971, the fields in question and almost all of the surrounding land were purchased or optioned by a local developer who began to construct homes on the site. Despite this, it was hoped that perhaps the operation could be handled in certain greenbelt areas within the development which would be beneficial for both the project and the developer. Subsequent negotiations on this subject proved otherwise, as the financial and operational conditions that were suggested by the developer did not appear feasible. The costs would have vastly exceeded the funds available for purchase of the lands and the restrictions would have seriously hindered the success of the project.

Investigations were then conducted to find a new site for the recharge operations. One important criterion for the alternative site was that it be located on government-owned or controlled land. This would avoid the necessity for the purchase or lease of the property, and would give the government control over the operation and full possession of the facility upon completion of the project.

In selecting an alternate site, the new primary treatment plant was used as a center and all the government holdings within a radius of three miles were determined from tax records. These included territorial government, federal government, and Virgin Islands Port Authority lands (see Figure 11). The current and future uses for the land were determined. Much of the land, although presently not used, was scheduled for development in the immediate future.

A study was then made of the general soil and geological conditions existing at each site. For the soils investigations, two reports published by the Soil Conservation Service of the U.S. Department of Agriculture (USDA) proved extremely useful. These were: Soils and Their Interpretations for Various Uses, St. Croix, American Virgin Islands (McKinzie et al., 1965) and Soil Survey, Virgin Islands of the United States (Rivera et al., 1970). They delineated the soils and their engineering and agricultural uses throughout the island. Their concern has been with the characteristics of the profile of the upper 60 in. (152 cm) of the soil. This layer is of primary interest to the project due to its ability to permit infiltration and percolation of the water to be recharged. An interpretive map in the first publication which was of great value was entitled, "The soil limitations for residences with individual septic tanks." These limitations were based on many of the characteristics such as percolation rate, shrink-swell behavior, depth to water table, etc., that would also apply to the artificial recharge operation. On this map the soil conditions were interpreted as providing slight, moderate, or severe limitations to the use of individual septic tanks. This information is shown on Figure 12. Areas showing slight limitation were those considered most suitable for the project, although others were considered.

Geological conditions have been characterized by Cederstrom (1950) and Robison (1972) in separate U.S. Geological Survey (USGS) publications concerning groundwater on St. Croix. This geological information, modified by observations in the field, is shown in Figure 13. This was an aid in outlining the possible groundwater flow, the

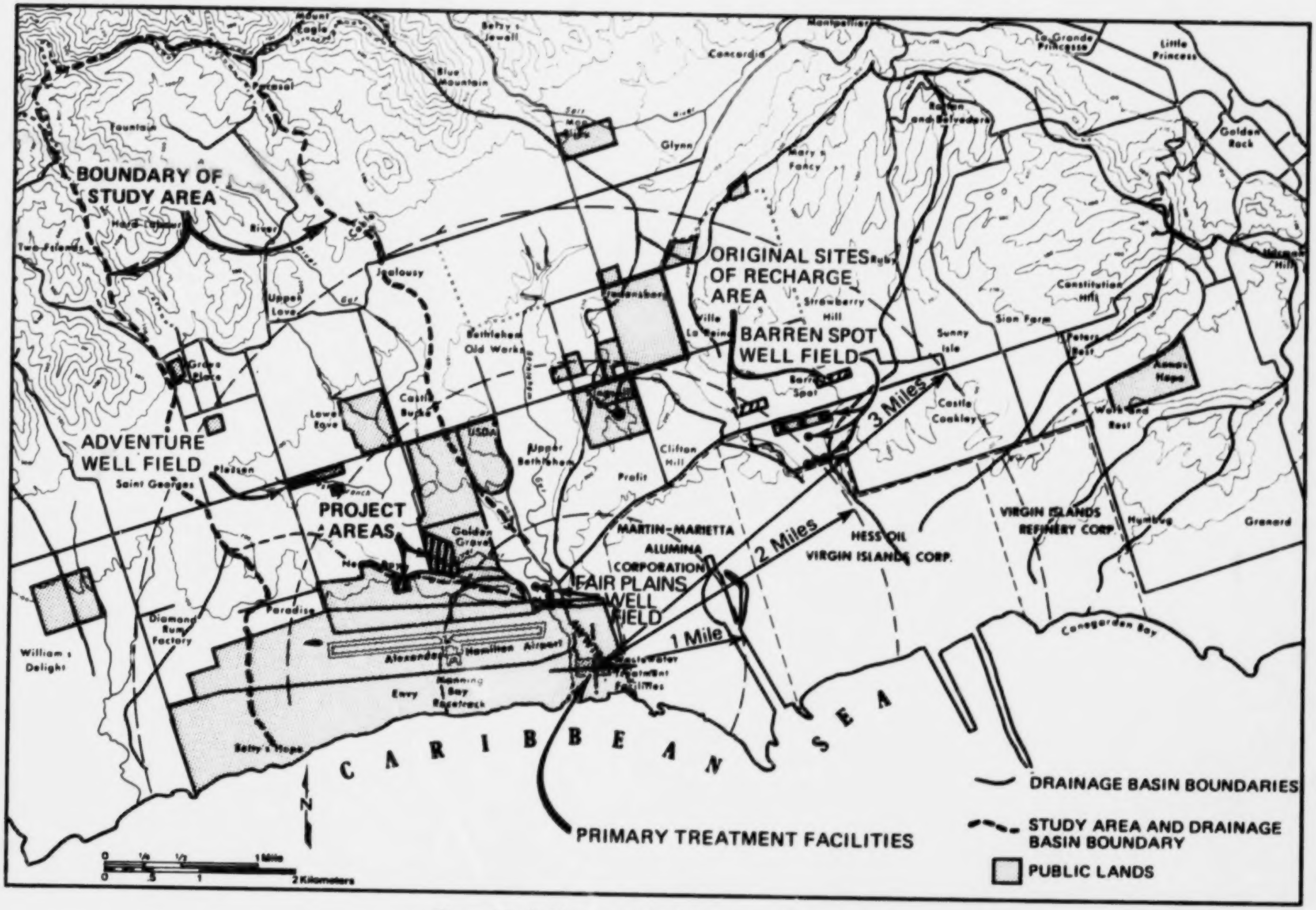

BOUNDARY OF STUDY AREA
ADVENTURE WELL FIELD
PROJECT AREAS
ORIGINAL SITES OF RECHARGE AREA
BARREN SPOT WELL FIELD
FAIR PLAINS WELL FIELD
MARTIN-MARIETTA ALUMINA CORPORATION
HESS OIL VIRGIN ISLANDS CORP.
VIRGIN ISLANDS REFINERY CORP.
1 Mile
2 Miles
3 Miles
PRIMARY TREATMENT FACILITIES
CARIBBEAN SEA
Mount Eagle
Betty's Jewell
Blue Mountain
Concordia
Montpellier
La Grande Princesse
Little Princess
Golden Rock
Barren and Belvedere
Mary's Fancy
Glynn
Fountain
Two Friends
Upper Love
Jealousy
Bethlehem Old Works
Strawberry Hill
Sunny Isle
Sion Farm
Constitution Hill
Peters Rest
Annas Hope
Castle Coakley
Work and Rest
Barren Spot
Clifton Hill
Profit
Upper Bethlehem
USDA
Castle Burke
Lower Love
Grove Place
Saint Georges
Golden Grove
Paradise
Diamond Ruby Factory
William's Delight
Alexander Hamilton Airport
Manning Bay Racetrack
Envy
Betty's Hope
Wastewater Treatment Facilities
Humbug
Granard
Canegarden Bay
N
0 1/4 1/2 1 Mile
0 .5 1 2 Kilometers
DRAINAGE BASIN BOUNDARIES
STUDY AREA AND DRAINAGE BASIN BOUNDARY
PUBLIC LANDS

Figure 11. Public-owned lands in central St. Croix.

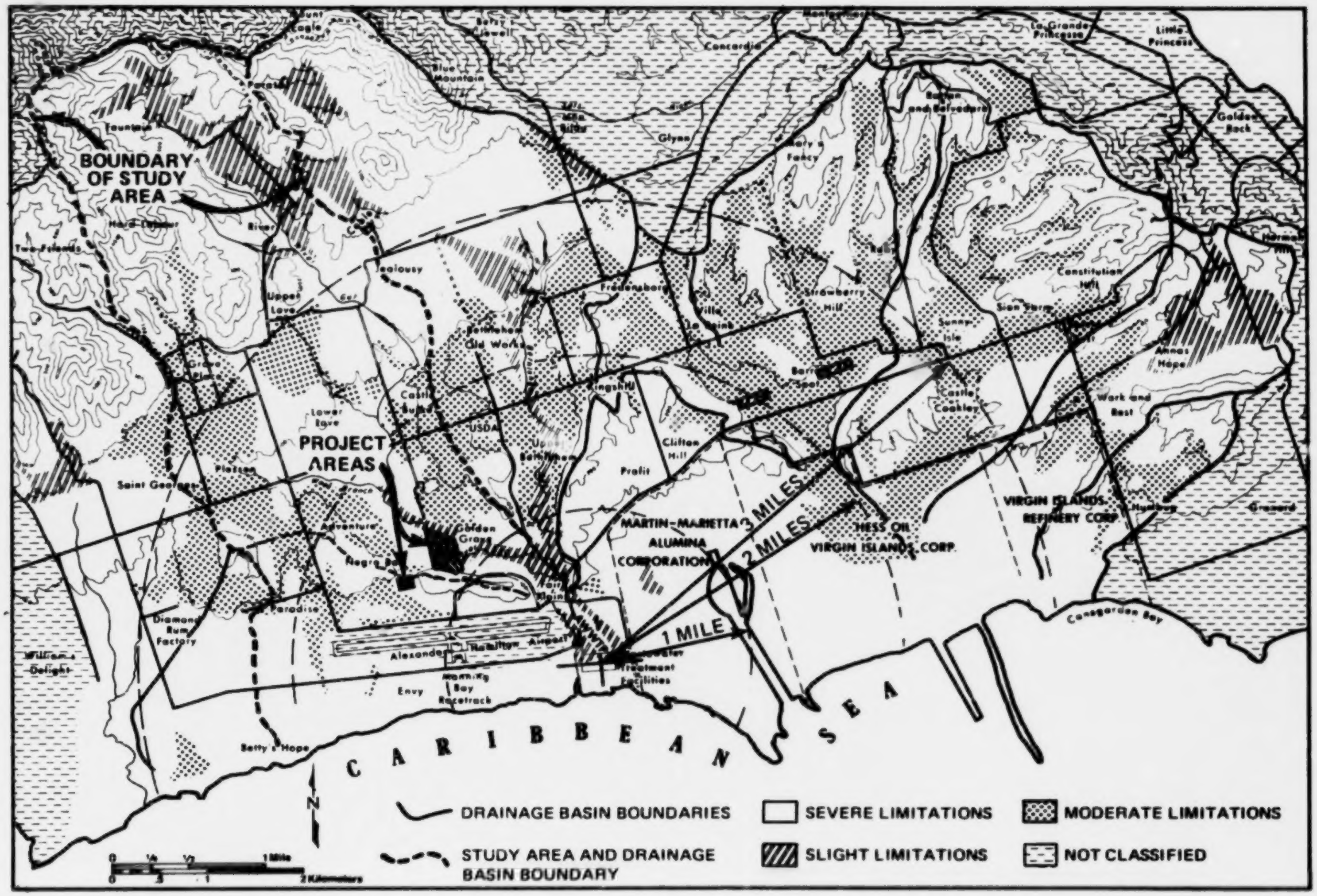

BOUNDARY OF STUDY AREA
PROJECT AREAS
MARTIN-MARIETTA ALUMINA CORPORATION
HESS OIL VIRGIN ISLANDS CORP.
VIRGIN ISLANDS REFINERY CORP.
1 MILE
2 MILES
3 MILES
CARIBBEAN SEA
Concordia
Blue Mountain
Glynn
Fredensborg
Strawberry Hill
Sunny Isle
Constitution Hill
Golden Rock
Little Princess
La Grande Princesse
Annas Hope
Work and Rest
Castle Coakley
Clifton Hill
Profit
Kingshill
Lower Love
Upper Love
Jealousy
Saint Georges
Paradise
Diamond Rum Factory
Williams Delight
Two Friends
Betty's Hope
Envy
Alexander Hamilton Airport
Manning Bay Racetrack
Golden Grove
Adventure
Negro Bay
Hovensa
Canegarden Bay
Granard
N
DRAINAGE BASIN BOUNDARIES
STUDY AREA AND DRAINAGE BASIN BOUNDARY
☐ SEVERE LIMITATIONS
▨ SLIGHT LIMITATIONS
▩ MODERATE LIMITATIONS
☐ NOT CLASSIFIED
0 1/4 1/2 1 Mile
0 .5 1 2 Kilometers

Figure 12. Soil limitations for septic tanks in central St. Croix.

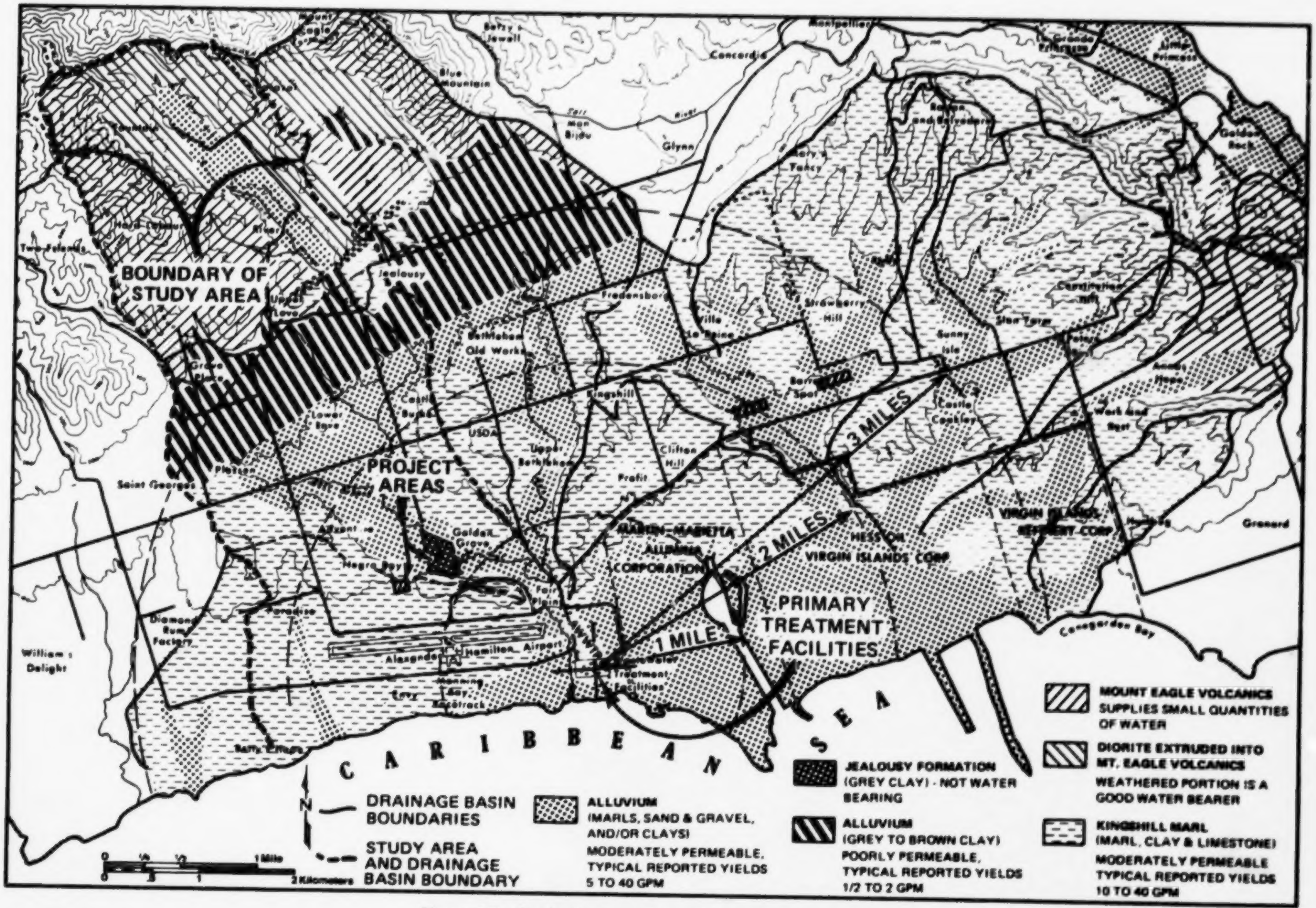

BOUNDARY OF STUDY AREA
PROJECT AREAS
PRIMARY TREATMENT FACILITIES
1 MILE
2 MILES
3 MILES
CARIBBEAN SEA
MARTIN-MARIETTA ALUMINA CORPORATION
HESS OIL VIRGIN ISLANDS CORP
VIRGIN ISLANDS REFINERY CORP
Concordia
Montpellier
Blue Mountain
Glynn
Jealousy
Upper Love
Lower Love
Castle Burke
Bethlehem Old Works
Fredensborg
Strawberry Hill
Sunny Isle
Castle Coakley
Barren Spot
Kingshill
Clifton Hill
Profit
Upper Bethlehem
USDA
Golden Grove
Negro Bay
Paradise
Diamond Rum Factory
William's Delight
Saint Georges
Plessen
Two Friends
Alexander Hamilton Airport
Manning Bay
Envy
Racetrack
Canegarden Bay
Granard
Anna's Hope
Work and Rest
Constitution Hill
Golden Rock
Little Princess
Grande Princesse
N
0 1/4 1/2 1 Mile
0 .5 1 2 Kilometers
DRAINAGE BASIN BOUNDARIES
STUDY AREA AND DRAINAGE BASIN BOUNDARY
ALLUVIUM (MARLS, SAND & GRAVEL, AND/OR CLAYS) MODERATELY PERMEABLE, TYPICAL REPORTED YIELDS 5 TO 40 GPM
JEALOUSY FORMATION (GREY CLAY) - NOT WATER BEARING
ALLUVIUM (GREY TO BROWN CLAY) POORLY PERMEABLE, TYPICAL REPORTED YIELDS 1/2 TO 2 GPM
MOUNT EAGLE VOLCANICS SUPPLIES SMALL QUANTITIES OF WATER
DIORITE EXTRUDED INTO MT. EAGLE VOLCANICS WEATHERED PORTION IS A GOOD WATER BEARER
KINGSHILL MARL (MARL, CLAY & LIMESTONE) MODERATELY PERMEABLE TYPICAL REPORTED YIELDS 10 TO 40 GPM

Figure 13. Geological conditions in central St. Croix.

relative subsurface permeabilities and the type of water-bearing formations to be expected. Observations made in the field produced specific information on soil conditions, current land usage, and existing facilities such as wells, roads, available power, etc. Several temporary roads were built and a trailer-mounted boring rig was used to make soil borings at various locations. Samples were evaluated in the field to determine the soil profile. Borings were made at three different depths--4, 7, and 20 ft (1.2, 2.1, and 6.1 m). The resulting 20-ft (6.1 m) holes were used for the placement of piezometric tubes while the 4- and 7-ft (1.2 and 2.1 m) holes were utilized for percolation tests. These latter two depths were selected to give information on percolation capabilities of shallow ponds versus a deeper trench arrangement. The results of the tests were used to indicate the relative capacity for percolation between sites. The data derived from the percolation tests in the four areas--Golden Grove, Negro Bay, Adventure, and Barren Spot--are illustrated in Figure 14.

Three sites were intensively investigated. These were in Estates Adventure, Golden Grove, and Negro Bay. The site at Adventure was discarded due to unfavorable soil conditions. The Negro Bay site indicated some good percolation values and no water table but appeared to contain some hard horizontal rock layers at depths from 8 to 20 ft (2.4 to 6.1 m). The presence of a hard limestone layer is a situation very typical of the Kingshill marls in which this site is located.

The Golden Grove site was very similar to the one at Barren Spot. Both are located in alluvial valleys above a major public well field and had relatively equivalent percolation results. However, the groundwater at Golden Grove is closer to the surface than that at Barren Spot.

The recharge area finally selected was one which made use of a dual-site concept. Two separate sites were used, one at Negro Bay and the other at Golden Grove. The sites selected were made up of two entirely different soil and geological conditions but are located quite close to each other. This permitted the use of one force main and holding tank to supply both areas with only a slight additional amount of piping. As these two formations comprise the bulk of the geological composition of the coastal plain, the data obtained are quite valuable in planning any expansion of the project to other areas of the island.

The Golden Grove portion was the primary site of recharging operations with the Negro Bay area used only for secondary experimentation. The Golden Grove project area is part of a larger parcel owned by the territory which is being developed into a governmental complex. The entire parcel is 94 acres (38 ha) and will ultimately be the site of a large building complex including an adult correctional facility, a juvenile detention center, and the Public Safety Headquarters. At the time of the initial studies the entire

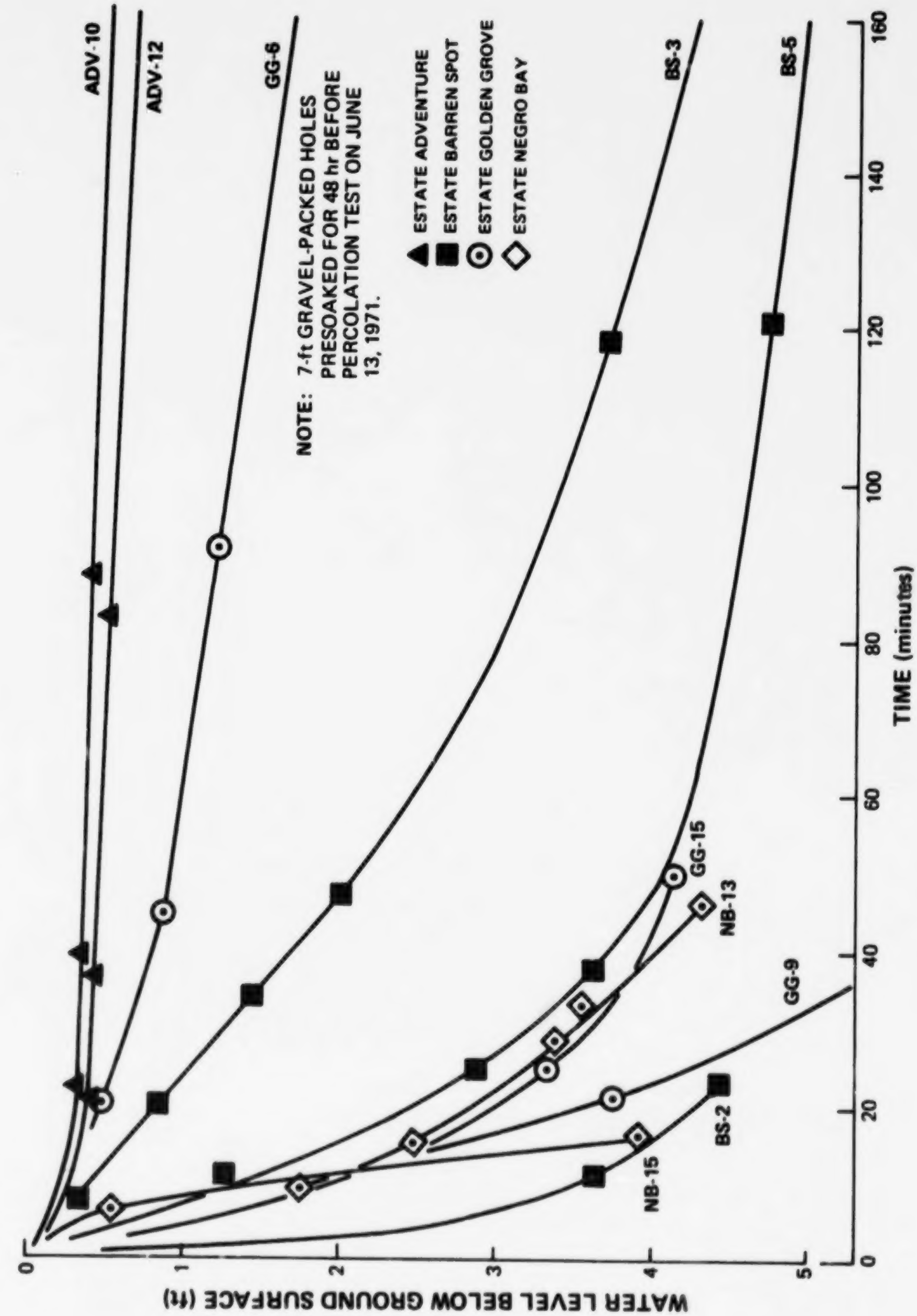


Figure 14. Results of percolation tests made at recharge sites under investigation.

area appeared untouched and was overgrown with scrub growth. Presently, the adult correctional facility and the public safety building have been constructed.

In using this parcel, the permanent installations involved with the recharging operations were located so that they will not interfere with any of the future buildings planned for the area. This again acted as another imposed restriction in the selection of land for recharging. After extensive discussions, several small areas of the parcel were set aside for project use by Lieutenant Governor Maas who was supervising the development of the parcel at that time. These areas were generally adjacent to the course of a meandering stream, River Gut, which winds through the parcel.

The basic geological formation is an alluvial valley with the soil types classified as being in the Coamo, Fraternidad, and Fredensborg series (see Table 1). The actual soil boundaries are not sharp in this area and the existence of some nonconforming lenses in the soil profiles is common. The topographic features in the area where the groundwater recharge operations in Estate Golden Grove will take place are shown in Figure 15.

About one mile (1.6 km) down the alluvial valley is the Fair Plains well field which is the major well field on the island with an average production of about 0.24 mgd (908 cu m/day). It is this well field that will be ultimately affected by the recharging operations at Golden Grove.

The Negro Bay site consists of about 8 acres (3.3 ha) spread over a slight saddle between two low hills. The underlying formation is the Kingshill marl. The major soils in this area are classified in the Fredensborg and Aguilita series (see Table 1). Borings made on the site indicated that a hard layer of limestone existed under most of the area at a depth of 8 to 20 ft (2.4 to 6.1 m). This has a mild anticlinal shape with an axis in a northeasterly direction and a slope of about 3 degrees. Recharging operations took place on the south side of the axis.

Work in this secondary site was largely of an experimental nature to see if the marls would have any potential for artificial recharge as they are predominant along the coast of the central plain. Although the major soil types in the area are classified as having moderate to severe limitations for septic tank installations, initial on-site percolation tests produced favorable results.

After the selection of the recharge area was accomplished, a study area was defined for the project. This consisted of the surface drainage area both above and below the recharge sites plus some additional area to the south which was thought to be related by groundwater flow. Within the study area, wells were selected for monitoring water quality and water levels. These included wells which

TABLE 1. SOIL CLASSIFICATIONS IN THE PROJECT AREA

Soil Classification	Description
Aguilita Series	Gently sloping to steep, well drained soils that are shallow over soft limestone or marl. These soils formed in residuum derived from limestone. In a typical profile the surface layer is very dark grayish brown and light brownish gray gravelly clay loam about 6 in. (15 cm) thick. Below this is mixed very dark grayish brown firm calcareous gravelly clay loam that is 50 to 70 percent limestone fragments. The substratum, at a depth of about 10 inches, is mostly soft limestone but contains hard limestone concretions. The soft limestone material can be penetrated with a spade. Drainage is good, and the permeability is moderate. The water table is low.
Coamo Series	Gently sloping well-drained soils that are deep over volcanic and limestone rocks. These soils occur on alluvial fans and terraces. They formed in sediments derived from these rocks. The sediments range in texture from clay to sand. In a typical profile the surface layer is very dark grayish brown clay loam about 8 in. (20 cm) thick. It contains a few rock fragments. The subsoil is very dark grayish brown and yellowish brown, firm clay. It also contains a few rock fragments. The substratum, beginning at a depth of about 24 in. (61 cm), is yellowish brown, friable, calcareous clay loam stratified with sand and gravel.
Fraternidad Series	Moderately well drained soils that formed in clayey sediments derived from volcanic and limestone hills. In a typical profile the surface layer is very dark grayish brown clay about 13 in. (33 cm) thick. Below this, to a depth of about 62 in. (157 cm), is light olive brown calcareous, very firm clay. Drainage is moderately good. Permeability is slow.

TABLE 1 (CONTINUED).

Soil Classification	Description
Fredensborg Series	Well drained soils that formed in clayey, calcareous sediments over soft limestone or marl. These soils occur near coastal areas, in valleys, and on foot slopes below the limestone hills. In a typical profile the surface layer is very pale brown, very friable, calcareous silty clay loam. At a depth of about 20 in. (51 cm) is a very pale brown, soft marl or limestone.

The information for this table was adapted from the publication, Soil Survey, Virgin Islands of the United States —1970.

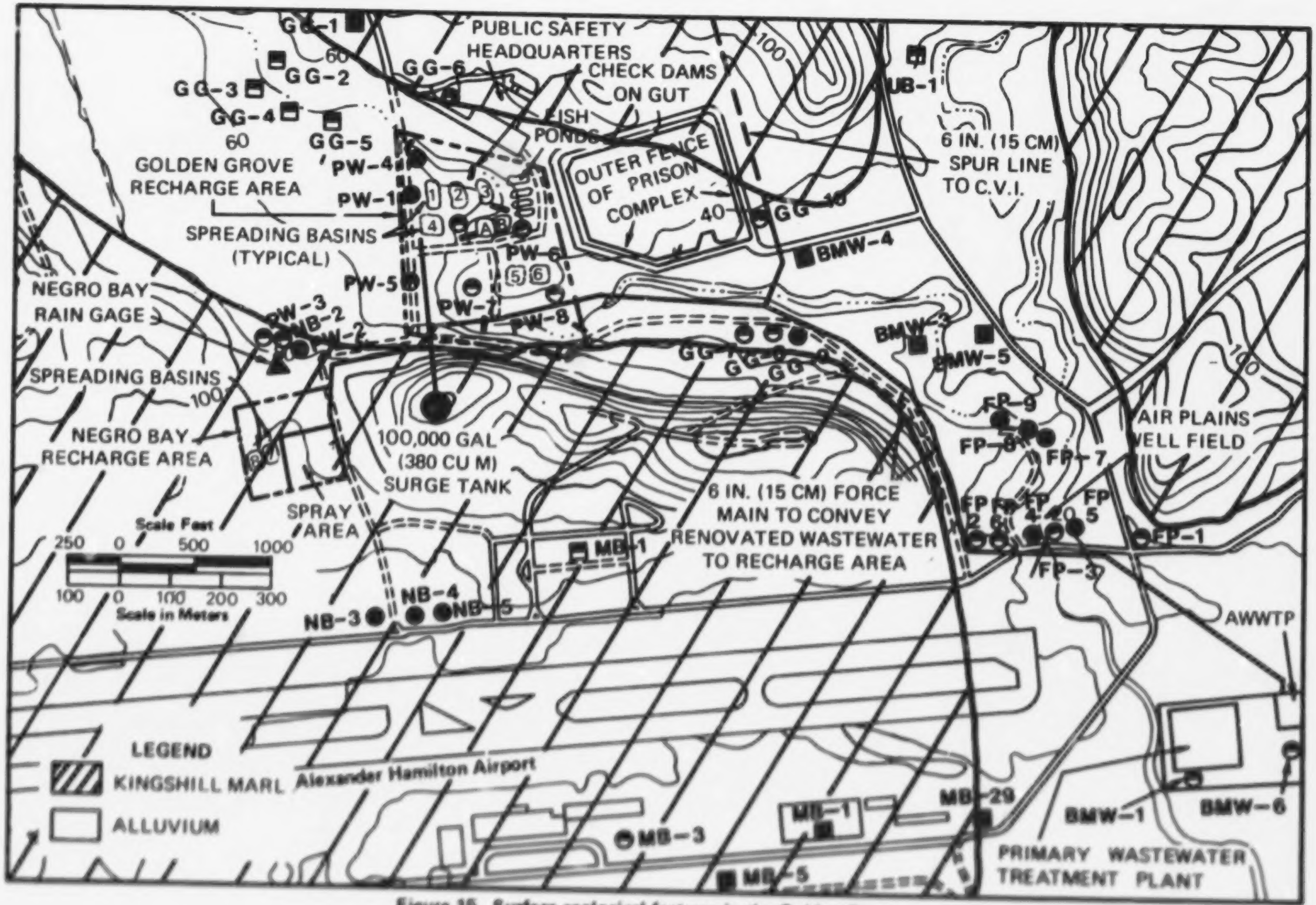

GG-1
GG-2
GG-3
GG-4
GG-5
GG-6
60
PUBLIC SAFETY HEADQUARTERS
CHECK DAMS ON GUT
FISH PONDS
OUTER FENCE OF PRISON COMPLEX
40
GG-10
UB-1
6 IN. (15 CM) SPUR LINE TO C.V.I.
GOLDEN GROVE RECHARGE AREA
PW-1
PW-2
PW-3
PW-4
PW-5
PW-6
PW-7
PW-8
1 2 3 4 A B 5 6
SPREADING BASINS (TYPICAL)
BMW-4
BMW-3
BMW-5
NEGRO BAY RAIN GAGE
NB-2
SPREADING BASINS
100
NEGRO BAY RECHARGE AREA
100,000 GAL (380 CU M) SURGE TANK
GG-7
GG-8
GG-9
FP-9
FP-8
FP-7
AIR PLAINS WELL FIELD
6 IN. (15 CM) FORCE MAIN TO CONVEY RENOVATED WASTEWATER TO RECHARGE AREA
FP 2
FP 6
FP 4
FP 5
FP-1
FP-3
SPRAY AREA
Scale Feet
250 0 500 1000
100 0 100 200 300
Scale in Meters
MB-1
NB-3
NB-4
NB-5
AWWTP
LEGEND
KINGSHILL MARL
ALLUVIUM
Alexander Hamilton Airport
MB-3
MB-1
MB-29
MB-5
BMW-1
BMW-6
PRIMARY WASTEWATER TREATMENT PLANT

Figure 15. Surface geological features in the Golden Grove area.

were above and below the recharge sites and some which were entirely out of the drainage basin to use as controls.

DESCRIPTION OF THE STUDY AREA

The study area is outlined in Figures 11, 12, 13, and 16. Figure 16 shows the area in detail including the existing wells and recharge sites. This study area is about 8 sq miles (20.7 sq km) and consists mainly of the drainage area for an intermittent stream called River Gut. The main portion of this stream, referred to as the East Branch, originates from springs located within Fountain Valley and flows south-southeast through the area for a distance of about 6 miles (9.7 km).

The northern part of the study area begins at the ridges of the hills which surround Fountain Valley where they delineate the drainage into the valley and downstream through River Gut. The ridge line here ranges from 300 to 1,000 ft (91 to 305 m) in elevation and the slopes fall off sharply to the undulating valley floor.

Once south of the line which runs from the villages of Grove Place to Coble, the study area becomes a gently sloping flat plain that continues to the shore about 3 miles (4.8 km) to the south.

Low eroded hills on the southern end of the area divert the flow of River Gut slightly to the east as they direct its course through a gap in the hills known as Fair Plains. It is at this gap where one of the government's largest well fields, the Fair Plains well field, is located.

The east and west branches of River Gut wind through the study area in a streambed that is generally depressed 2 to 10 ft (0.5 to 3 m) below the land surface. Along its banks are older more established trees which were left untouched during the years of cultivation. A wide variety of trees are represented including, but not limited to, mango (*Mangifera indica*), hog plum (*Spondias mombin*), West Indian almond (*Terminalia catappa*), royal palm (*Roystonea borinquena*), and licorice (*Pithecellobium saman*). These trees range from 40 to 50 ft (12 to 15 m) in height and tower over the lower scrub growth of the adjacent fields.

Visually, the animal density and diversity has appeared low in the study area with the most frequently seen animals being the mongoose (*Herpestes auropunctatus*) and the white-tailed deer (*Odocoileus virginiana*).

Until about 1968 almost all of the flat portions of the study area were used for pasture and for the cultivation of sugarcane by the Virgin Islands Corporation. Aside from the golf course which occupies the upper end of the study area, most of the rest of the land has been

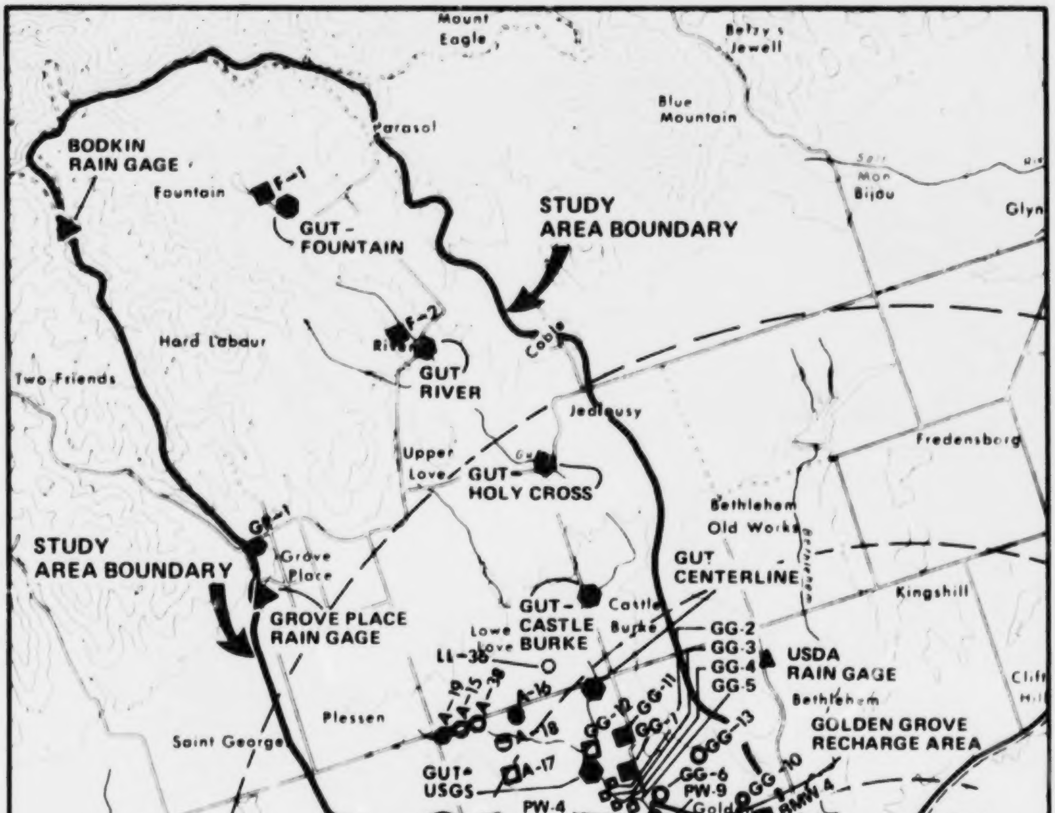

Mount Eagle
Betsy's Jewell
Blue Mountain
Parasol
Mon Bijou
Glyn
BODKIN RAIN GAGE
Fountain
F-1
GUT-FOUNTAIN
STUDY AREA BOUNDARY
F-2
River
GUT RIVER
Hard Labour
Two Friends
Cane
Jealousy
Fredensborg
Upper Love
GUT-HOLY CROSS
Bethlehem Old Works
GUT CENTERLINE
Kingshill
GG-1
Grove Place
STUDY AREA BOUNDARY
GROVE PLACE RAIN GAGE
GUT-CASTLE BURKE
Castle Burke
Lower Love
LL-38
USDA RAIN GAGE
GG-2
GG-3
GG-4
GG-5
Bethlehem
Clifton Hill
A-16
A-15
A-18
A-17
GG-12
GG-11
GG-1
GG-13
Plessen
Saint George
GOLDEN GROVE RECHARGE AREA
GUT-USGS
GG-6
PW-9
GG-10
BMW-4
Golden Grove
PW-4
PW-1
PW-5
PW-8
PW-6
PW-7
BMW-3
BMW-5
FP-9
FP-8
FP-7
FP-5
FP-1
FP-3
NB-1
P-3
P-1
P-2
P-4
PW-2
NB-2
PW-3
GG-9
GG-8
GG-7
MB-1
AWWTP
Diamond Rum Factory
NEGRO BAY RAIN GAGE
William's Delight
MB-3
Alexander Hamilton Airport
MB-2
MB-5
MB-4
FP-2
FP-6
FP-4
Wastewater Treatment Facilities
C-38
E-39
NEGRO BAY RECHARGE AREA
Envy
E-1
Bay
Racetrack
MB-29
BMW-1
BMW-6
BMW-2
Betty's Hope
CARIBBEAN SEA
N
0
1/4
1/2
1 Mile
0
.5
1
2 Kilometers
LEGEND
● PUBLIC WELLS - PUMPED
⊖ PUBLIC WELLS - NOT PUMPED
■ PRIVATE WELLS - PUMPED
▣ PRIVATE WELLS - NOT PUMPED
⬢ SURFACE WATER SAMPLING STATION
▲ RAIN GAGE

Figure 16. Well locations in the study area.

allowed to naturally shift from pasture and cane to scrub growth. This process has almost completely driven out the ratoon crops of sugarcane by the rapid growth of Guinea grass (Pancium maximum) and the spread of acacia (Acacia tortuosa), tan-tan (Leucaena glauca), and thibet (Albizia lebbek) trees throughout the area. The change in vegetation has been assisted by several fires which often sweep the area during the dry seasons.

The main activity in the study area over the past 5 years has been the clearing of land by bulldozing. Generally only a small section of land is affected at a time but probably the whole area has been cleared once and some parts several times. Fires have also occurred in the area during times of drought. These usually will burn entire fields and act as a clearing agent. Regrowth from both causes is rapid and with the proper rainfall the main effects of clearing can disappear within 3 to 6 months.

In 1972 a major wastewater interceptor was built alongside the main and west branches of River Gut to serve the village of Grove Place. About the same time a 100-unit multistory housing project, Croixville, was built just north of the Adventure well field and two large governmental complexes, the Public Safety Headquarters and an adult correctional facility, were constructed in Estate Golden Grove. In conjunction with the construction of the correctional facility, about 1,000 ft (305 m) of River Gut was widened, straightened, and the trees removed as part of a flood control plan.

Portions of the Golden Grove recharge area have been cleared and planted in Bermuda grass, which gives better service and is easier to maintain than the native Guinea grass. During clearing operations the larger more desirable thibet and licorice trees were preserved on the site.

The Negro Bay site, which is on the Kingshill marl, has probably not been used agriculturally for at least 35 years. The soil is not as rich as other parts of the coastal plain and the area had been part of the U.S. Army base during World War II. Here the scrub growth was lower in height but much denser and predominantly in thorn trees such as acacia. The cleared areas have quickly moved to revegetation with Guinea grass.

Groundwater Geology

Study Area. The knowledge of the groundwater geology in the study area is somewhat fragmentary since it depends largely on gathering information through actual coring of the mantle, either for intellectual gratification or the actual construction of a well. This has always been a rather expensive pursuit and currently costs approximately $10/ft ($32.80/m) for a 6-inch (15 cm) uncased hole using a cable tool drilling rig.

An interpretive sketch of the geological formations in the coastal plain that probably affect the flow and location of groundwater in the study area is presented in Figure 17. This sketch is based on a variety of source information but most notably on observations by project personnel, Public Works Department well logs, and publications by Cederstrom (1941, 1950) and Whetten (1963).

The major portion of the study area is in the coastal plain which gently slopes up from the south shore to the hills of the Northside Range. The geological base for this plain in the study area is the Jealousy formation. Cederstrom (1950) mentions that this is a gray clay, or mudstone, which contains some calcareous conglomerate in its makeup. This formation is referred to locally as blue clay and it has a reputation, not unfounded, for being an impermeable nonwater-bearing stratum. Test drillings by Cederstrom found that this formation had a thickness, adjacent to the study area, of over 1,398 ft (426 m) and hence when a local well driller encounters this formation, he generally drills no further.

Lying on the Jealousy formation is the Kingshill marl which Cederstrom (1950, p. 21) describes as consisting of "buff-to-white moderately thick bedded limestone, alternating with soft cream or white marl."

The limestone portion is generally quite hard while the marl is comparatively soft and easily cut with a knife. The vertical permeability of this formation is extremely low due to the intact limestone layers, while the horizontal permeability can be quite high due to solution cavities or other voids in the formation.

On the coastal plain the hills at Jealousy and Lower Love are made up only partially from Kingshill marl while all of the hills south of the Centerline Road consist of this formation. It probably formed the entire plain but has been eroded by streams and the eroded beds replaced by local alluvial deposition. This can best be seen in the geological cross section of Estate Golden Grove, in Figure 18, where a U-shaped valley has been eroded from the marl and filled with the alluvial clays, sands, and gravels that make up the upper, most recent formation on the plain.

This alluvial material becomes thinner as it proceeds northward to the lower slope of the Northside Range. Within the alluvium a number of defined gravelly aquifers exist separated by thicker layers of silty clay. This clayey soil ranges from moderately to highly impermeable, depending on the location. The existence of alluvium is no guarantee of an underlying aquifer, as apparently the deposition of sands and gravels has been nonuniform both horizontally and vertically, which has resulted not only in the lack of aquifers in the alluvium in some locations but isolated sand and gravel lenses in others.

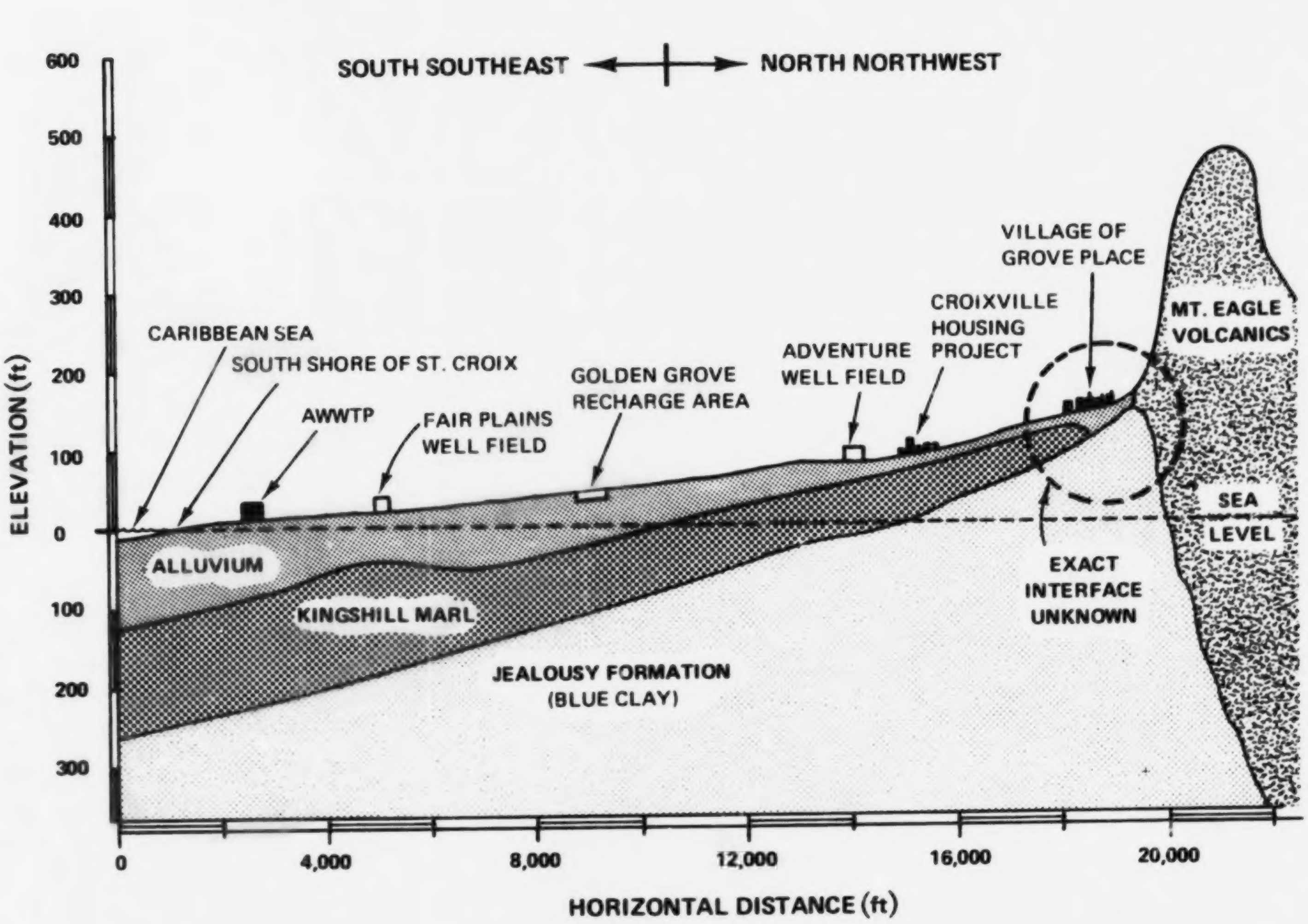

SOUTH SOUTHEAST
NORTH NORTHWEST
ELEVATION (ft)
600
500
400
300
200
100
0
100
200
300
CARIBBEAN SEA
SOUTH SHORE OF ST. CROIX
AWWTP
FAIR PLAINS WELL FIELD
GOLDEN GROVE RECHARGE AREA
ADVENTURE WELL FIELD
CROIXVILLE HOUSING PROJECT
VILLAGE OF GROVE PLACE
MT. EAGLE VOLCANICS
SEA LEVEL
EXACT INTERFACE UNKNOWN
ALLUVIUM
KINGSHILL MARL
JEALOUSY FORMATION (BLUE CLAY)
0
4,000
8,000
12,000
16,000
20,000
HORIZONTAL DISTANCE (ft)

Figure 17. Geological cross section of the coastal plain.

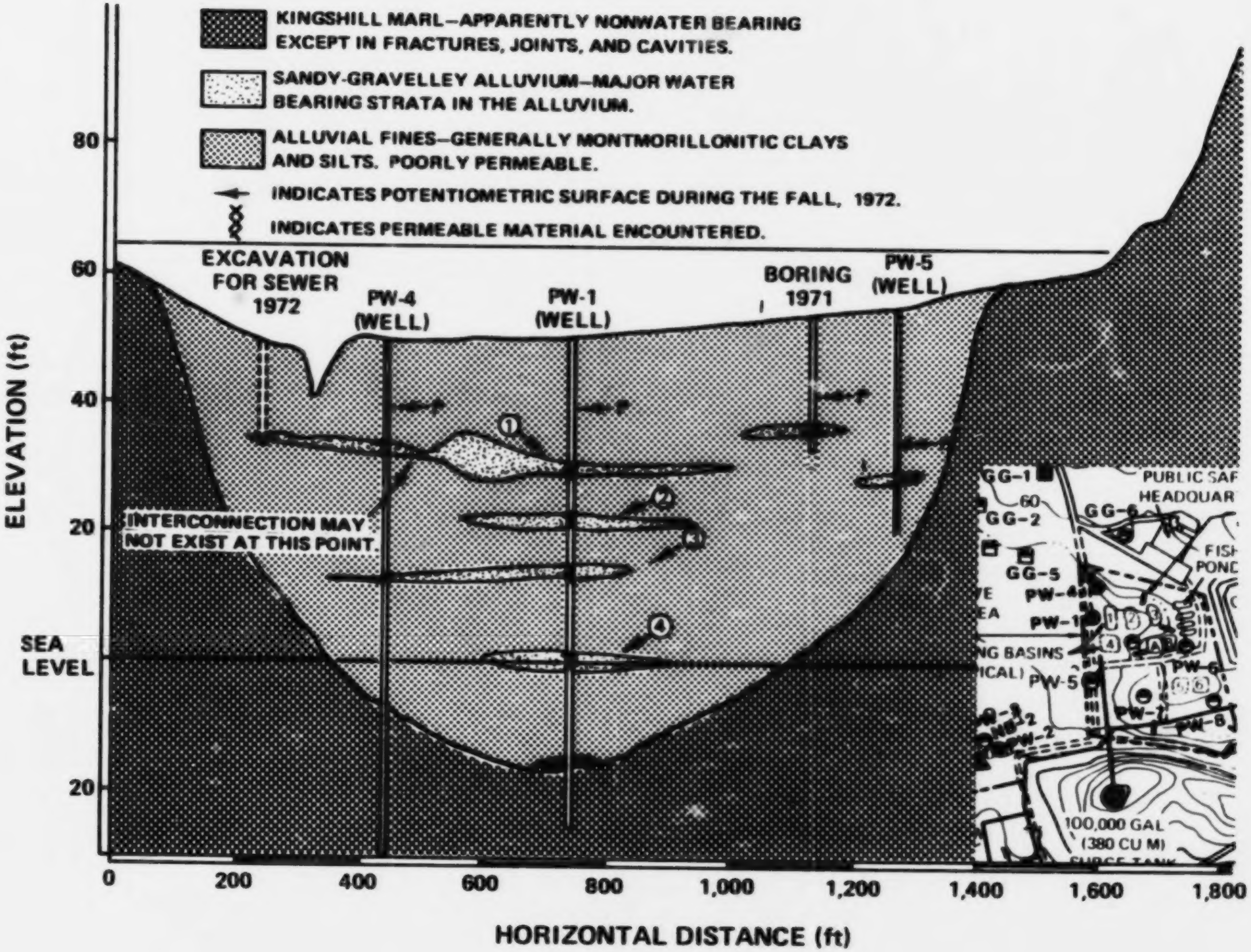

KINGSHILL MARL—APPARENTLY NONWATER BEARING EXCEPT IN FRACTURES, JOINTS, AND CAVITIES.
SANDY-GRAVELLEY ALLUVIUM—MAJOR WATER BEARING STRATA IN THE ALLUVIUM.
ALLUVIAL FINES—GENERALLY MONTMORILLONITIC CLAYS AND SILTS. POORLY PERMEABLE.
INDICATES POTENTIOMETRIC SURFACE DURING THE FALL, 1972.
INDICATES PERMEABLE MATERIAL ENCOUNTERED.
EXCAVATION FOR SEWER 1972
PW-4 (WELL)
PW-1 (WELL)
BORING 1971
PW-5 (WELL)
INTERCONNECTION MAY NOT EXIST AT THIS POINT.
①
②
③
④
ELEVATION (ft)
80
60
40
20
SEA LEVEL
20
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
HORIZONTAL DISTANCE (ft)
GG-1
60
GG-2
GG-6
GG-5
PUBLIC SAF
HEADQUAR
FISH
POND
PW-4
PW-1
PW-5
PW-6
PW-7
PW-8
PW-2
NG BASINS
ICAL)
100,000 GAL
(380 CU M)

Figure 18. Geological cross section of the Golden Grove area at right angles to the streambed.

As seen in Figure 17 the alluvium and Kingshill marl formations terminate in the north by contact with the Mount Eagle volcanics. Cederstrom (1950, p. 16) mentions that "a large part of the material is volcanic in origin, that much of it is stratified, and that some limestone beds are interbedded with volcanics. Dark fine-grained massive, laminated or slaty rocks, hard thin- to thick-bedded limestone, and spotted or porphyritic rocks are most common." The Mount Eagle volcanics generally yield minor amounts of groundwater in their weathered portions and in the rock fractures and crevices. The Mount Eagle volcanics make up the vast majority of the Northside Range and it is believed that much of the water in the aquifers of the coastal plain has its origin in these hills. The exact structure of the interface, defined by the dashed circle in Figure 17, between the coastal plain and the Northside Range is unknown and merely hypothesized in this sketch. It is certainly a subject worthy of further research efforts on the part of local geologists.

Not shown in Figure 17 is the geological structure of Fountain Valley, which is in the northernmost part of the study area and contains the springs which initially supply River Gut. Fountain Valley has an alluvial valley floor but its walls are made up of not only Mount Eagle volcanics but an intrusive igneous rock referred to by Whetten (1968) as Fountain Gabbro. A plan view of the geological formations exposed at the surface in central St. Croix is shown in Figure 19.

Naturally the geology of the recharge areas is of great concern to the project since this determines the ultimate disposition of the recharged water after it enters the soil. As was mentioned, two recharge areas were selected which are adjacent to each other but yet geologically dissimilar. One contains alluvial deposits and the other marls. These areas, Golden Grove and Negro Bay, contain the geological formations that make up the vast majority of the land held by the local government and therefore would be available for future groundwater recharge utilization.

GOLDEN GROVE RECHARGE AREA

Using information obtained from old well logs, potentiometric data plus borings, and new wells constructed in the area as part of this project, three diagrams of the assumed geological configuration in the Golden Grove area have been constructed. These are shown in Figures 15, 18, and 20. Basically the area consists of alluvial deposits laid down on top of the Kingshill marl. The alluvial deposit is the one of concern in this area as far as recharging is concerned. As shown in Figure 18 the deposit varies in thickness up to about 70 ft (21.3 m). Its predominant constituent is a montmorillonitic clay which tends to be somewhat impervious.

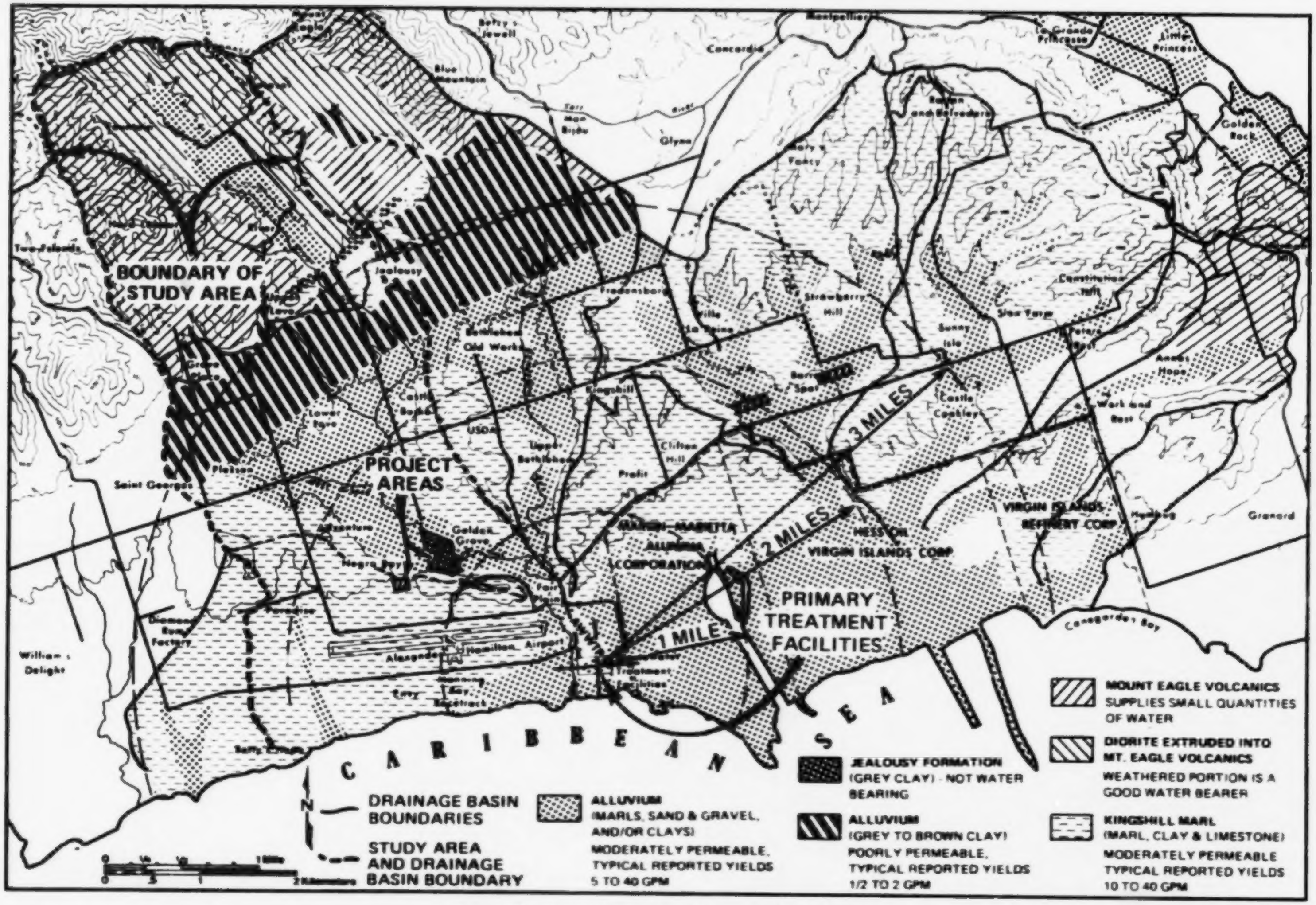
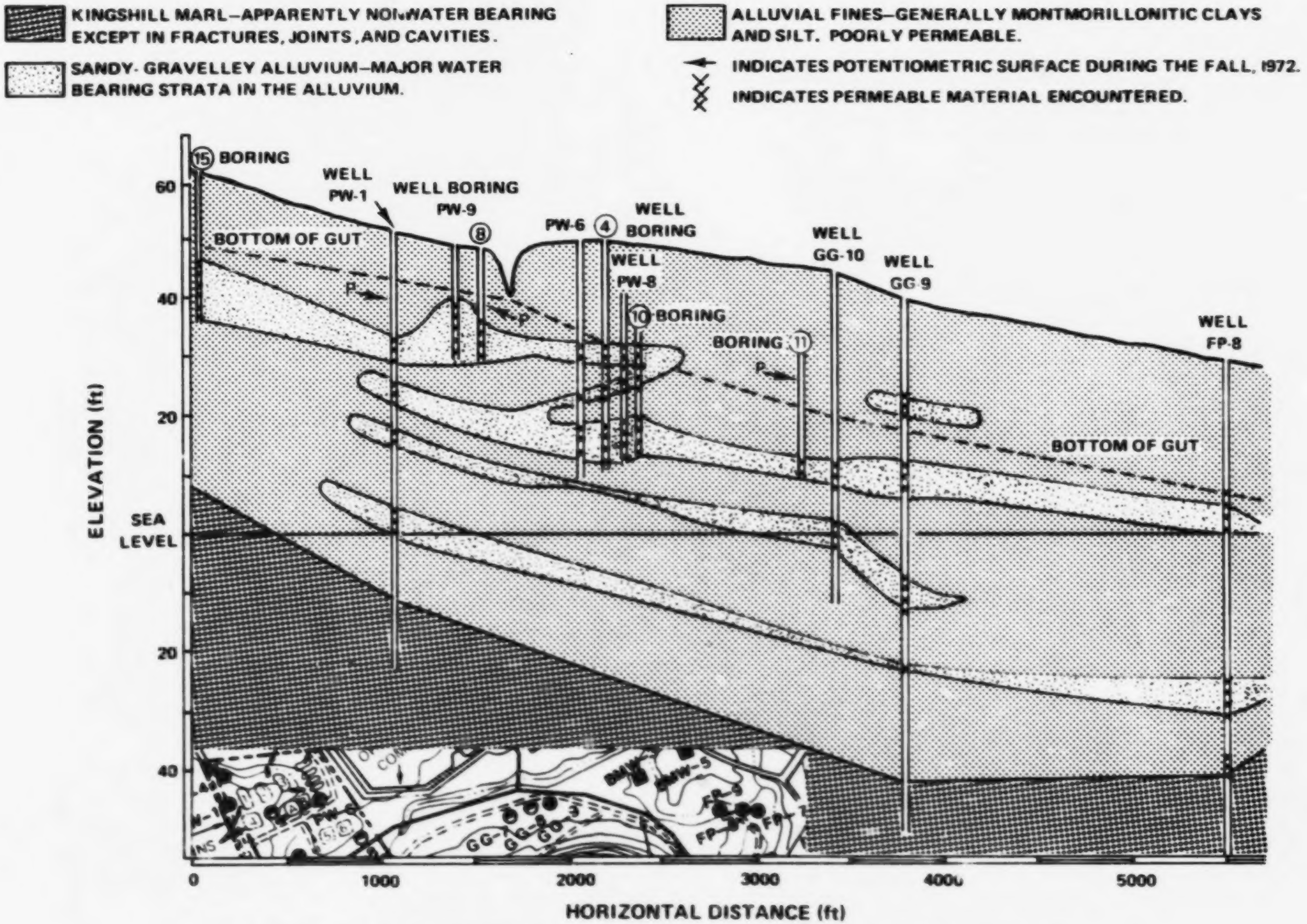

BOUNDARY OF STUDY AREA
PROJECT AREAS
PRIMARY TREATMENT FACILITIES
1 MILE
2 MILES
3 MILES
CARIBBEAN SEA
MARTIN-MARIETTA ALUMINA CORPORATION
HESS OIL VIRGIN ISLANDS CORP
VIRGIN ISLANDS REFINERY CORP.
Montpellier
La Grande Princesse
Little Princess
Betsy's Jewell
Concordia
Blue Mountain
Glynn
Golden Rock
Barren and Belvedere
Betsy's Fancy
Jealousy
Fredensborg
Strawberry Hill
Constitution Hill
Slob Farm
Sunny Isle
Castle Coakley
Anna's Hope
Work and Rest
Kingshill
Clifton Hill
Old Works
Bethlehem
Upper Bethlehem
Castle Burke
USDA
Lower Love
Profit
Golden Grove
Negro Bay
Saint Georges
Two Friends
Diamond Ruby Factory
William's Delight
Alexander Hamilton Airport
Envy
Manning Bay
Racetrack
Sally Canal
Treatment Facilities
Hardeship
Granard
Canegarden Bay
N
DRAINAGE BASIN BOUNDARIES
STUDY AREA AND DRAINAGE BASIN BOUNDARY
ALLUVIUM (MARLS, SAND & GRAVEL, AND/OR CLAYS) MODERATELY PERMEABLE, TYPICAL REPORTED YIELDS 5 TO 40 GPM
JEALOUSY FORMATION (GREY CLAY) - NOT WATER BEARING
ALLUVIUM (GREY TO BROWN CLAY) POORLY PERMEABLE, TYPICAL REPORTED YIELDS 1/2 TO 2 GPM
MOUNT EAGLE VOLCANICS SUPPLIES SMALL QUANTITIES OF WATER
DIORITE EXTRUDED INTO MT. EAGLE VOLCANICS WEATHERED PORTION IS A GOOD WATER BEARER
KINGSHILL MARL (MARL, CLAY & LIMESTONE) MODERATELY PERMEABLE TYPICAL REPORTED YIELDS 10 TO 40 GPM
0 1/4 1/2 1 Mile
0 .5 1 2 Kilometers

Figure 19. Geological map of the coastal plain.



KINGSHILL MARL—APPARENTLY NONWATER BEARING EXCEPT IN FRACTURES, JOINTS, AND CAVITIES.
SANDY- GRAVELLEY ALLUVIUM—MAJOR WATER BEARING STRATA IN THE ALLUVIUM.
ALLUVIAL FINES—GENERALLY MONTMORILLONITIC CLAYS AND SILT. POORLY PERMEABLE.
INDICATES POTENTIOMETRIC SURFACE DURING THE FALL, 1972.
INDICATES PERMEABLE MATERIAL ENCOUNTERED.
⑮ BORING
WELL PW-1
WELL BORING PW-9 ⑧
PW-6 ④ WELL BORING
WELL PW-8
⑩ BORING
BORING ⑪
WELL GG-10
WELL GG 9
WELL FP-8
BOTTOM OF GUT
BOTTOM OF GUT
P
P
P
ELEVATION (ft)
60
40
20
SEA LEVEL
20
40
0
1000
2000
3000
4000
5000
HORIZONTAL DISTANCE (ft)

Figure 20. Geological cross section of the Golden Grove area along the plane of the streambed.

Spaced within the alluvial clays are thin horizontal aquifers of clayey-sandy-gravelly material. These aquifers are usually no more than 2 ft (0.61 m) in thickness and are probably not well interconnected except due to boreholes in the vicinity and possibly at the junction of two streambeds near the Fair Plains well field.

Groundwater studies have demonstrated that the potentiometric head throughout the valley reflects the confined condition of the water within the aquifer and does not represent a free water table. In most of the study area and the island in general, an unconfined water table does not exist. The water in the aquifers moves from northeast to southeast below the recharge area. It must be kept in mind that Figure 17 has the vertical scale exaggerated 15 times for clarity and that the actual slope of the ground surface and aquifers is less than 1 degree from the horizontal.

The upper aquifer, in Figure 18, is the aquifer mainly affected by the surface recharge activities in the area. The material between this aquifer and the ground surface tends to be a nonhomogeneous soil with great variations taking place in the soil types across the valley floor. The upper 18 inches of soil is a dark clay with the lower material being lighter in color and containing a higher percentage of silt and sand. This sand is of the silica variety, which is rare on the island since calcareous sand is the predominant form on the shoreline. Several beds of sand have been encountered in the region but unfortunately they were not extensive in area nor is it certain that they are interconnected. The gut which winds through the valley depends on a base flow from springs located at the head of the stream and other areas where the streambed cuts into an aquifer and thus flows when the groundwater level is above the elevation of the bed.

The method of recharging proposed in the Golden Grove area was by the use of spreading basins and existing streambeds. The limiting factor was expected to be the permeability of the soil between the recharging activity and the upper aquifer. The bottoms of the spreading basins were therefore excavated below the extremely clayey surface layer to utilize the increased permeability of the lower silty horizons. This scheme did prove feasible and the recharge operations were conducted mostly in the basins.

The streambed in the Golden Grove area is below the surrounding land from 2 to 8 ft (0.6 to 2.4 m) and thus somewhat closer to the aquifer in question. Six small check dams 2 to 3 ft (0.6 to 0.9 m) high were constructed in the streambed to hold the recharge water to facilitate infiltration and percolation. Unfortunately the floods in October, 1974, severely damaged all of these check dams before recharge experiments in the streambed could be carried out.

NEGRO BAY RECHARGE AREA

The geology of this area consists of calcareous material of various types. Explorations in the recharge area were carried out by shallow borings, to a depth of about 15 ft (4.6 m), and wells were constructed to a maximum of 150 ft (46 m). A hypothesized geological cross section of the Negro Bay recharge area is shown in Figure 21.

The surface layer of about 6 to 12 in. (15 to 30 cm) is a dark clay while the subsoil is of a calcareous nature, white to buff in appearance and composed of a combination of a soft powderlike material interspersed with cemented nonstratified marl. Beginning at about 10 ft (3 m) below grade there are alternate hard and soft stratifications of limestones and marl which continue to a depth of about 150 ft (46 m). Here the Kingshill marl rests on a montmorillonitic mudstone geologically designated as the Jealousy formation and commonly referred to on the island as blue clay. Stratifications within the Kingshill marl in this area are about 2 to 6 in. (5 to 15 cm) thick. The movement of groundwater through the marl is by solution cavities which apparently are rather small, generally having cross sections of no more than about 20 sq in. (129 sq cm). These solution cavities seem to run in specific strata in the formation but are not always interconnected within the same strata.

During the summer of 1972 two wells were drilled, PW-2 and PW-3, which confirmed the existence of alternate hard and soft layers within the Kingshill marl. The formation was dry until the drilling operation penetrated a hard limestone layer at an elevation of about 2 ft (0.61 m) below sea level and encountered water. This water proved to be under pressure and rose in the well to about 15 ft (4.6 m) above sea level. The two wells were constructed 250 ft (76 m) apart and encountered water at the same elevation. The groundwater was confined in both cases but production in one well was estimated at a rate of only 2 gpm (0.13 l/sec) while the other produced at about 60 gpm (3.8 l/sec). Currently the latter well is being used by the Virgin Islands' government as part of its public supply.

Recharging in the Negro Bay area involved the use of the unconsolidated marls in the upper 10 ft (3 m) of the existing formation. Numerous soil borings were made by the project in this area to map out the extent of the unconsolidated marl and the underlying limestone anticline. Long-term percolation tests indicated that the upper softer marls were capable of receiving large quantities of recharge water. This concept was tested on a full scale with reclaimed wastewater, using surface methods such as spray irrigation and spreading basins.

The recharged water from the site was expected to percolate down to the first hard layer about 10 ft (3 m) below the surface which would place it on the south slope of a mild anticline which has a

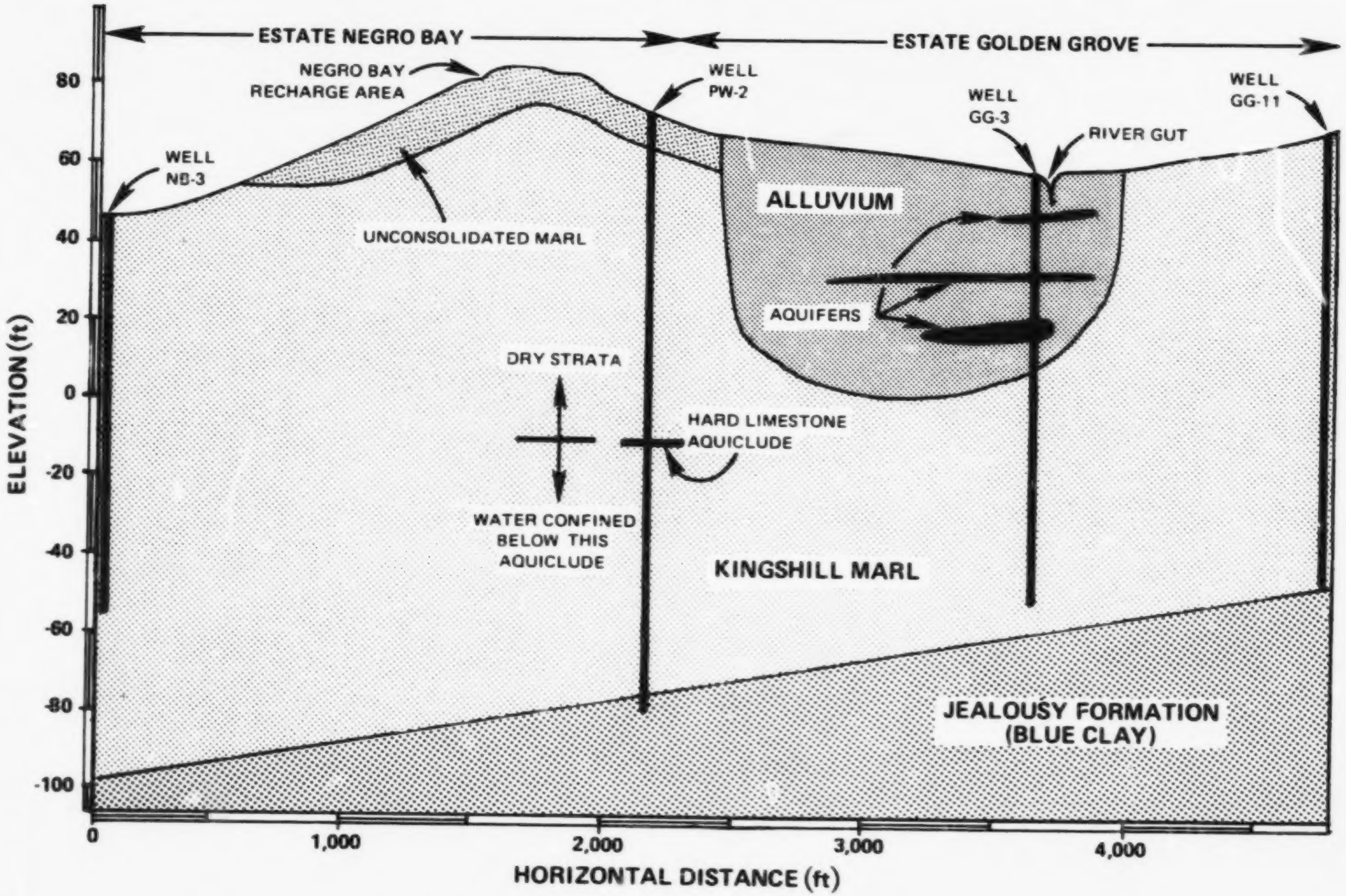

ESTATE NEGRO BAY
ESTATE GOLDEN GROVE
NEGRO BAY RECHARGE AREA
WELL PW-2
WELL GG-3
RIVER GUT
WELL GG-11
WELL NB-3
UNCONSOLIDATED MARL
ALLUVIUM
AQUIFERS
DRY STRATA
HARD LIMESTONE AQUICLUDE
WATER CONFINED BELOW THIS AQUICLUDE
KINGSHILL MARL
JEALOUSY FORMATION (BLUE CLAY)
ELEVATION (ft)
80
60
40
20
0
-20
-40
-60
-80
-100
0
1,000
2,000
3,000
4,000
HORIZONTAL DISTANCE (ft)

Figure 21. Geological cross section of the Negro Bay area.

northeasterly axis. Indications were that this hard layer was contiguous and probably impermeable. The water would then mound and be available for recovery. This system would not involve any mixing with the existing groundwater in the area as the groundwater is located in strata about 80 ft (24 m) below the surface where it was extremely improbable that the recharged water could reach.

Unfortunately the rate of infiltration and percolation of the recharged water in Negro Bay did not prove to be up to expectation and recharging operations were suspended in August, 1974.

HYDROLOGICAL DEVELOPMENTS IN THE STUDY AREA

Groundwater

In the normal groundwater recharge cycle on St. Croix, the heavier rains occur between August and December; these tend to fill up the aquifers which then slowly empty until the following fall when they are refilled. There is also a short rainy season in the spring and occasionally other times of heavy rains which aid in recharging, but basically the aquifers must depend on these fall rains or any long series of heavy rains which come in a pattern to permit maximum infiltration and minimum runoff to the sea. Large amounts of rain alone are unsatisfactory as much of the water can be lost in runoff. The long-term relationship between the rain pattern and the water levels in some wells in the study area is shown in Figure 3.

The groundwater in the study area at Golden Grove is entirely dependent on infiltration possible from a tributary area of about 5.6 sq miles (14.4 sq km). Much of this area is surfaced with tight clays and hence is limited as to its potential for infiltration and permeability. The major aquifers in the Golden Grove area are of gravelly sand with a thickness of less than 2 ft (0.6 m) and an estimated width which varies from 250 to 1,000 ft (76 to 305 m). There are several individual aquifers interspaced by clayey strata. The major recharge activity appears to take place in the area north of Centerline Road after which the groundwater flows south-southeast to the ocean.

This water is tapped in numerous places by government and private wells which draw down on the stored water. A measure of the amount of water existing in the aquifer at any time is the potentiometric head on the aquifer at various points along the flow network to the sea. Water level recorders were installed in various key locations along the flow route which monitored the water levels in these wells. Some accuracy is lost in these measurements since the wells generally penetrate, and thus interconnect, more than one aquifer.

At the time of the first interim report (Black, Crow and Eidsness, Inc.) in June, 1972, the study area was affected by a surplus of groundwater. This hindered borings and required the formulation of plans to reduce the amount of groundwater in the recharging area to provide capacity in the aquifers to test the feasibility of recharging. Plans to alleviate this situation were carried out, but by the time of the second interim report (Black, Crow and Eidsness, Inc.), in October, 1973, a contrary situation had occurred in that a general deficit of precipitation during the preceding 17 months had produced a circumstance where some of the aquifers were nearly empty and others were producing at a reduced capacity.

This deficit condition continued for an additional year and marked one of the worst droughts in recent history. On July 22, 1974, the island was proclaimed a federal drought disaster area. Many wells went dry during this time and others, near the sea, had a significant rise in salt content due to saltwater intrusion. Although the drought condition was alleviated in August, 1974, by the first significant rains in months, it definitely came to a close by November, 1974, when record rains caused severe flooding over large portions of the island. On November 15, 1974, the island was again declared a federal disaster area, only this time it was due to flooding. Half the average annual rainfall was received within a period of 25 days and the soil could not handle the disposal of the water by infiltration. As a result, billions of gallons of water ran off into the surrounding sea.

Although some recharge of the aquifers did occur during this period, it was not concomitant with the amount of precipitation experienced. Piezometric levels rose, but in the subsequent 8 months only scant rainfall occurred and the levels rapidly dropped again. By July, 1975, many of the piezometric levels had dropped close to the previous spring's drought level. Although the quick shift from one extreme to another in the water situation was caused by an unusual rain condition, the overall long-range pattern of going from a surplus to a deficit of water seems to be a regular, though unpredictable, phenomenon for the island. This points up the utility of having a method of artificial groundwater recharge working on the island which will permit the leveling off of groundwater production at a constant, predictable high rate, regardless of the climatic conditions.

Surface Water

The only significant surface flow in the study area occurs in River Gut. In general, its base flow is dependent on the groundwater level in the area. Runoff from storms makes up its flow on only a small percentage of its total flow days. However, these runoffs can be quite considerable and only a few days of heavy runoff can represent the majority of the total annual flow. The amount of this runoff contributing to streamflow is dependent on the rainfall pattern, soil moisture, land surface, and vegetation conditions.

During 1971 through early 1972 there was a continuous base flow in River Gut as it passed through Golden Grove. But then due to the depressed water table and lack of adequate precipitation, there was no flow in the lower half of River Gut from March, 1972, to October, 1974, with the exception of two days of storm runoff and one week as a result of a broken water main near the Adventure well field. A flash flood occurred in October, 1974, and an even larger flood came again in the following month. A sustained flow followed in River Gut which continued until the latter part of December, 1974. From then until September, 1975, there has been no flow in the streambed in the Golden Grove area.

WATER AND WASTEWATER SYSTEMS ON THE ISLAND

The potable water distribution system on the island of St. Croix has developed in small stages as finances permitted and politics dictated. Its initial function was to service the two towns of Christiansted and Frederiksted and the central sugar factories built at several locations in the island. From this it was expanded or converted to serve the expanding needs of the populace. Currently both towns are supplied with potable water and portions of the central coastal plain are included in the system.

The wastewater collection system was relatively simple up to 1970. Both towns collected and discharged their untreated wastewater, via outfalls, into their respective harbors. Inland, most homes used septic tanks while large housing developments employed small package plants with discharge onto the fields or out to sea.

In 1966 a consultant surveyed the obvious defects in the existing system and submitted a report and master plan (Camp, Dresser and McKee, Inc.) for the collection, treatment, and ultimate disposal of wastewater on St. Croix. This plan has been followed with only minor deviations and today is well on its way toward completion.

Basically the plan called for a single treatment facility on the south shore about midway between Christiansted and Frederiksted. The wastewater from the two towns and the central portion of the island would be transported to this facility by gravity interceptors and force mains, given primary treatment, and discharged to sea via a long ocean outfall. The system and its design are excellent; however, since the designers were apparently neither informed by the local government of its desire for eventual water reuse nor able to foretell the generally unpredictable future on the island, the system was not designed to cope with the complex problem of wastewater reclamation. This fact, combined with the system of water distribution, has caused considerable problems for the reclamation project.

The system of water distribution and wastewater collection on the island is crucial to the successful reuse of water on St. Croix. The distribution system has a variety of point sources which add water of differing qualities to the system at various locations. Table 2 names these point sources and lists the quantity and quality of the water added to the system. Figures 22 and 23 show the sources of wastewater and outline the relationship between chloride content from these sources and the flows in the entire collection system on the island. Figure 22 shows the situation as it was in June, 1974, when the reclamation project was in operation. At this time only the central portion of the island was contributing wastewater to the treatment plant at Bethlehem Middle Works.

This limited area of collection is the reason that the amount of wastewater available for processing in the AWWTP was so limited during the operational phase of the project. The water used in this area is a combination of groundwater from the Adventure, Barren Spot, and Fair Plains well fields plus some of the desalinized water from the Martin Marietta Company. Additionally, of course, each building in the island supplies collected rainwater from its own cistern.

The most serious problem with the reuse of water on the island comes from the total dissolved solids (TDS) in the waste stream. Most notable are the chlorides which affect the taste of the water and its suitability for agricultural purposes. Table 2 shows the great range of chloride concentrations from the various sources. Some of this groundwater for the central area is mixed in the 10 mil gal (37,850 cu m) storage tank at Kingshill before distribution; but the final chloride content of water used, and hence wastewater produced, is really a function of the day-to-day production of each source. Figure 24 is a graph of the chloride content of the influent to the AWWTP during the operational phase of the project. The chloride content ranged from about 300 to 2,500 mg/l during this operational period.

Figure 23 shows the relationship of the chlorides in the various sources of wastewater and the flows in the entire collection system which went to the central primary treatment plant in September, 1975. The sources of wastewater have been increased by flows from the town of Frederiksted. Aside from a large increase in wastewater, there was now the addition of about 0.08 mgd (300 cu m) of seawater which is used in Frederiksted for flushing purposes in several of the major housing projects. This collection configuration became effective in October, 1974, with the activation of the wastewater pumping station in Frederiksted. The chloride content in the wastewater being processed at the AWWTP increased immediately to about 2,000 mg/l. This made the reclaimed wastewater unsuitable for present reuse purposes. The artificial recharge of groundwater was discontinued while the local government tried to resolve the problem. Although progress has been made towards resolution, the situation still existed in September, 1975.

TABLE 2. MAJOR WATER SOURCES ON ST. CROIX

Source	Average daily contribution to the water supply (mgd)	(cu m/day)	Average chloride content (mg/1)
Desalinized water			
WAPA Stern Rogers plant	0.74	2,800	2
Martin Marietta Alumina Co. plant	0.65	2,460	4
Groundwater			
Fair Plains well field	0.22	830	1,100*
Barren Spot well field	0.14	530	670
Adventure well field	0.09	340	230
Concordia well field	0.07	265	390
Mahogany Road-La Grange well field	0.13	490	250
Rainwater collected in cisterns			
Total of homes on island (estimate)	0.3	1,135	10

*Extremely variable, this value is based on a mean of the samples taken 1971-1974.

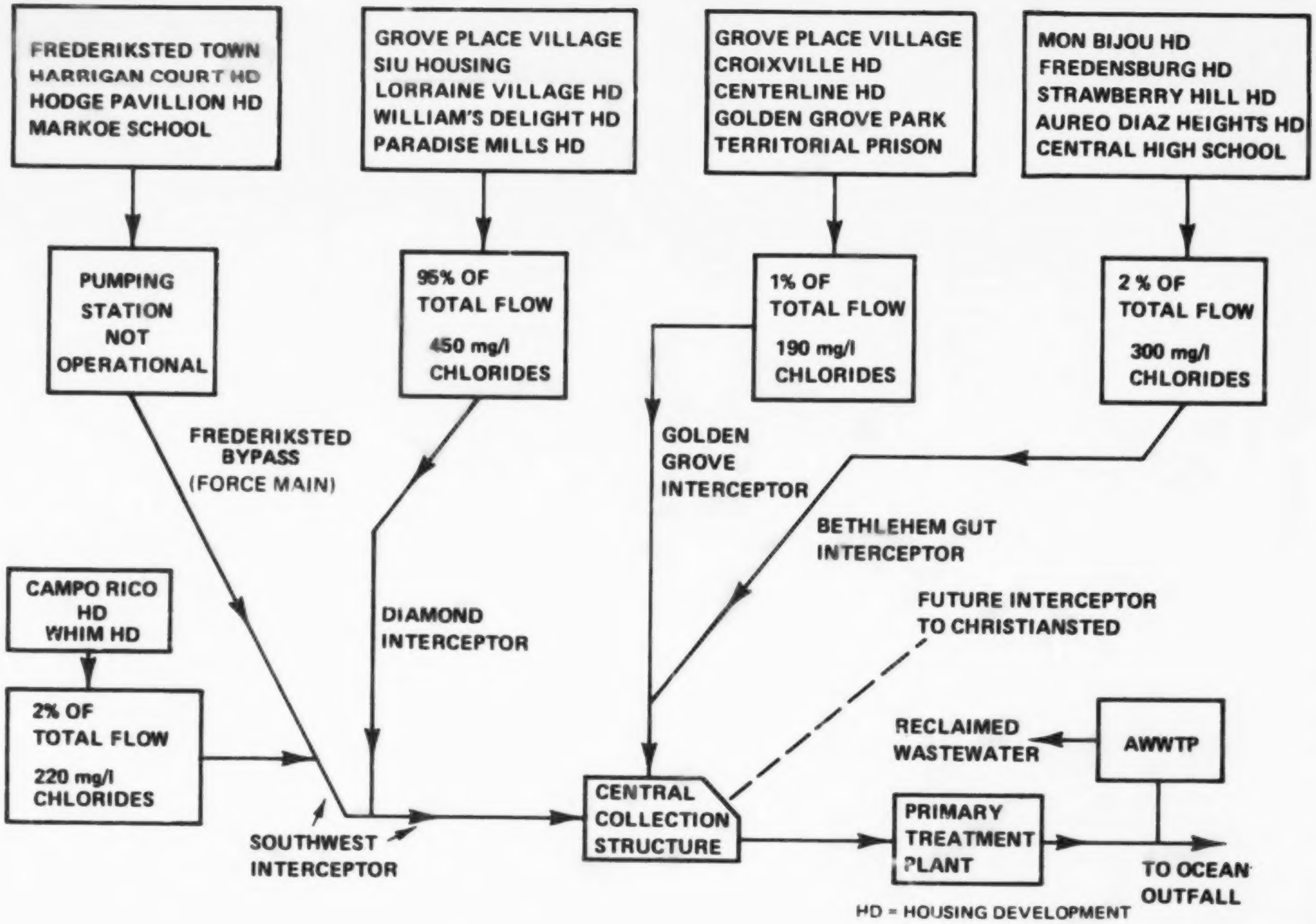

FREDERIKSTED TOWN
HARRIGAN COURT HD
HODGE PAVILLION HD
MARKOE SCHOOL
GROVE PLACE VILLAGE
SIU HOUSING
LORRAINE VILLAGE HD
WILLIAM'S DELIGHT HD
PARADISE MILLS HD
GROVE PLACE VILLAGE
CROIXVILLE HD
CENTERLINE HD
GOLDEN GROVE PARK
TERRITORIAL PRISON
MON BIJOU HD
FREDENSBURG HD
STRAWBERRY HILL HD
AUREO DIAZ HEIGHTS HD
CENTRAL HIGH SCHOOL
PUMPING STATION NOT OPERATIONAL
95% OF TOTAL FLOW
450 mg/l CHLORIDES
1% OF TOTAL FLOW
190 mg/l CHLORIDES
2 % OF TOTAL FLOW
300 mg/l CHLORIDES
FREDERIKSTED BYPASS
(FORCE MAIN)
GOLDEN GROVE INTERCEPTOR
BETHLEHEM GUT INTERCEPTOR
CAMPO RICO HD
WHIM HD
DIAMOND INTERCEPTOR
FUTURE INTERCEPTOR TO CHRISTIANSTED
2% OF TOTAL FLOW
220 mg/l CHLORIDES
RECLAIMED WASTEWATER
AWWTP
CENTRAL COLLECTION STRUCTURE
SOUTHWEST INTERCEPTOR
PRIMARY TREATMENT PLANT
TO OCEAN OUTFALL
HD = HOUSING DEVELOPMENT

Figure 22. The source of wastewater flows in June, 1974.

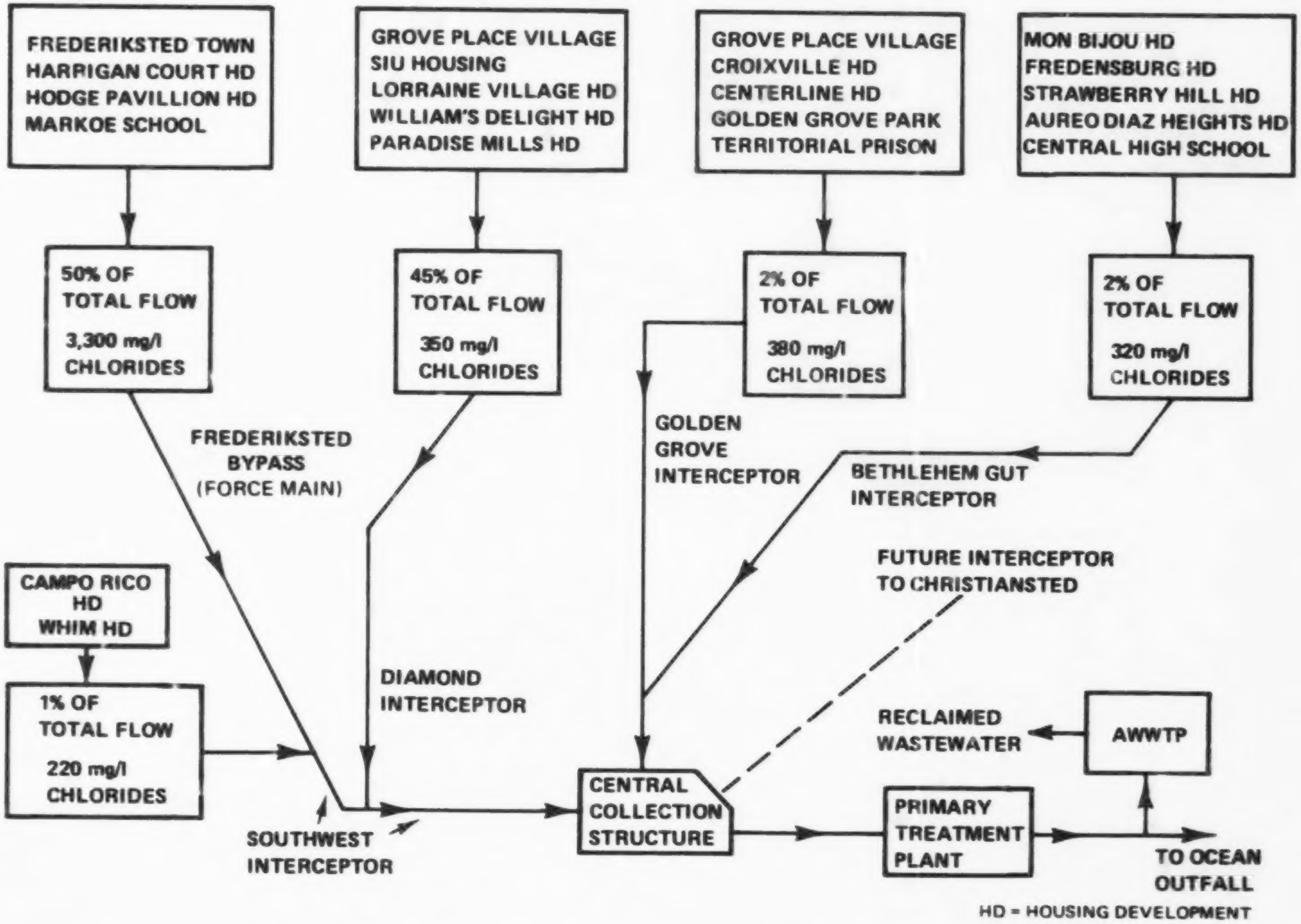

FREDERIKSTED TOWN
HARRIGAN COURT HD
HODGE PAVILLION HD
MARKOE SCHOOL
GROVE PLACE VILLAGE
SIU HOUSING
LORRAINE VILLAGE HD
WILLIAM'S DELIGHT HD
PARADISE MILLS HD
GROVE PLACE VILLAGE
CROIXVILLE HD
CENTERLINE HD
GOLDEN GROVE PARK
TERRITORIAL PRISON
MON BIJOU HD
FREDENSBURG HD
STRAWBERRY HILL HD
AUREO DIAZ HEIGHTS HD
CENTRAL HIGH SCHOOL
50% OF TOTAL FLOW
3,300 mg/l CHLORIDES
45% OF TOTAL FLOW
350 mg/l CHLORIDES
2% OF TOTAL FLOW
380 mg/l CHLORIDES
2% OF TOTAL FLOW
320 mg/l CHLORIDES
FREDERIKSTED BYPASS (FORCE MAIN)
GOLDEN GROVE INTERCEPTOR
BETHLEHEM GUT INTERCEPTOR
FUTURE INTERCEPTOR TO CHRISTIANSTED
CAMPO RICO HD
WHIM HD
1% OF TOTAL FLOW
220 mg/l CHLORIDES
DIAMOND INTERCEPTOR
SOUTHWEST INTERCEPTOR
CENTRAL COLLECTION STRUCTURE
RECLAIMED WASTEWATER
AWWTP
PRIMARY TREATMENT PLANT
TO OCEAN OUTFALL
HD = HOUSING DEVELOPMENT

Figure 23. The source of wastewater flows in September, 1975.

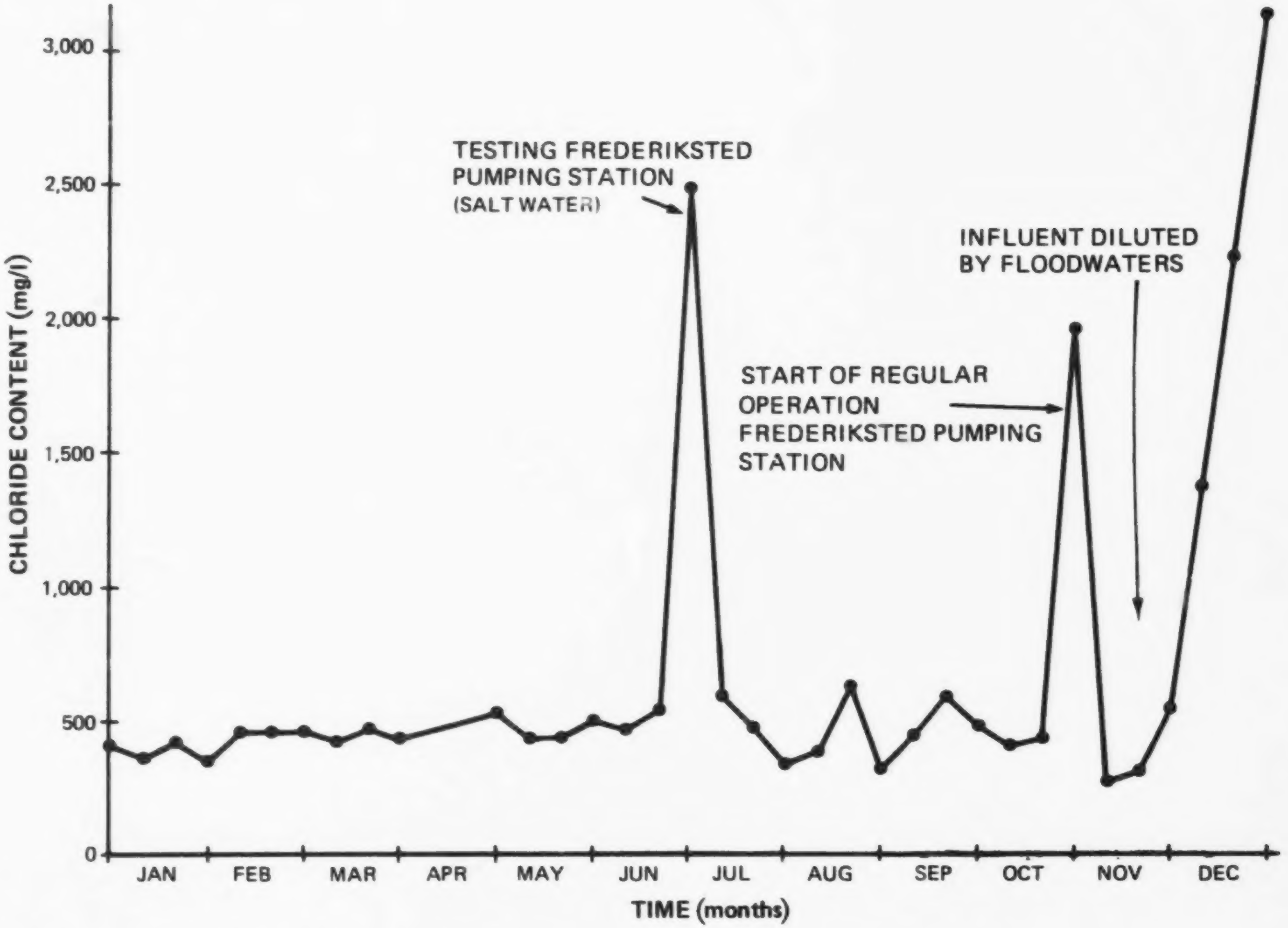


Figure 24. Chloride content of the incoming wastewater to the AWWTP in 1974.

SECTION VI

DESCRIPTION OF THE PROJECT FACILITIES

ADVANCED WASTEWATER TREATMENT PLANT (AWWTP)

Purpose

The purpose of the AWWTP within the project framework was to upgrade the quality of the wastewater to a level where it could be safely and efficiently used for artificial recharge of the groundwater on St. Croix.

Goal

The goal of the AWWTP was to produce a clear, odor-free effluent which would be extremely low in organics, suspended solids, and microorganisms. Certain operational guidelines were drawn up and, aside from normal organic reduction, it was desired that the effluent have a turbidity of less than 3 Formazin Turbidity Units (FTUs) and preferably less than 1. At the same time, the effluent should have a free chlorine residual (FCR) after a 30-minute contact time of 1 mg/l or more, at 1 FTU; and 3 mg/l or more, at 3 FTUs.

The purpose of using these guidelines was two-fold. One was the protection of public health and hence the desire to reduce exposure of the public to possible pathogenic organisms to a negligible degree. Additionally it was realized that the soil in the main recharge area was predominately clays and silts and that this type of soil could be expected to clog readily if any significant biological activity or mechanical entrapment took place. By adhering to the guidelines, it enabled the project to minimize these problems and efficiently utilize the small amount of land available for recharging.

Design Assumptions

In the design of the plant, certain assumptions were made. A discussion of the most significant of these follows with pertinent comments on their validity.

Assumption 1. The primary plant and the associated wastewater collection system in the western and central portions of the island would be completed and operating with a total flow of about 1 mgd (3,785 cu m/day) by the time the reclamation of wastewater began.

In actuality the construction of the plant and interceptor network was delayed at all stages, with the primary plant not being placed in operation until August, 1972, and the important western end of the collection system not being completed until October, 1974. Thus incoming wastewater flows were below expectation during the operational phase of the project.

Assumption 2. The incoming wastewater to the primary plant would have a high biochemical oxygen demand (BOD) and ammonia-nitrogen (NH_3-N) content.

The local environmental health officials on St. Croix were quite insistent on designing for a high incoming BOD. The basis for this idea, at the time, was quite reasonable. Several package treatment plants had been recently constructed in the territory to service various large housing developments. Although different types of plants were used, the results were often very poor as the high organic loading to the plants had caused them to operate badly and, in many cases, such as the package plant at Mon Bijou, to become a community nuisance. This high BOD was the result of low water usage, often only 15 to 40 gpd/person (57 to 151 l/day/person) due to the severe shortage and high cost of fresh water. A health department report (Grigg et al., 1971) on package treatment plants on neighboring St. Thomas, which has similar water problems, showed a range in BOD of incoming wastewater from 6 to 693 mg/l.

Since no interceptors existed at the time of design in the central portion of the island, with the exception of the vicinity of Mon Bijou, opportunities for testing were limited; and in view of the package plant problems, it does not seem like an unreasonable assumption. Samples of the incoming wastewater at the Mon Bijou plant and the Frederiksted pumping station in July, 1971, were analyzed and had a BOD of 1,000 and 260 mg/l, respectively; while the NH_3-N level was 90 and 56 mg/l, respectively. For design purposes it was estimated that the BOD to the secondary portion of the plant would range from 200 to 750 mg/l.

In actuality at the same time as the design of the AWWTP was taking place, construction began on numerous multistory housing projects in central and western St. Croix. These were completed in late 1973 and had a capacity for about 8,000 residents, which is about 20 percent of the population of the island. A decision was made to connect these units to the public potable water system and in most cases to supply unmetered water to the tenants as part of the basic monthly rental.

The result was a tremendous increase in the average water usage and a concomitant reduction in the BOD of the wastewater which entered the collection system from the central and western portions of the island. The mean value of the BOD, determined on a bimonthly basis during 1974, for incoming effluent for the AWWTP ranged from 68 to 140 mg/l. Hence the plant has plenty of excess aeration capacity.

Assumption 3. Surface methods of artificial recharge would be employed.

In actuality that is what happened.

Assumption 4. The saltwater flushing system in Frederiksted would be converted to fresh water to avoid contaminating the wastewater to be used for reclamation.

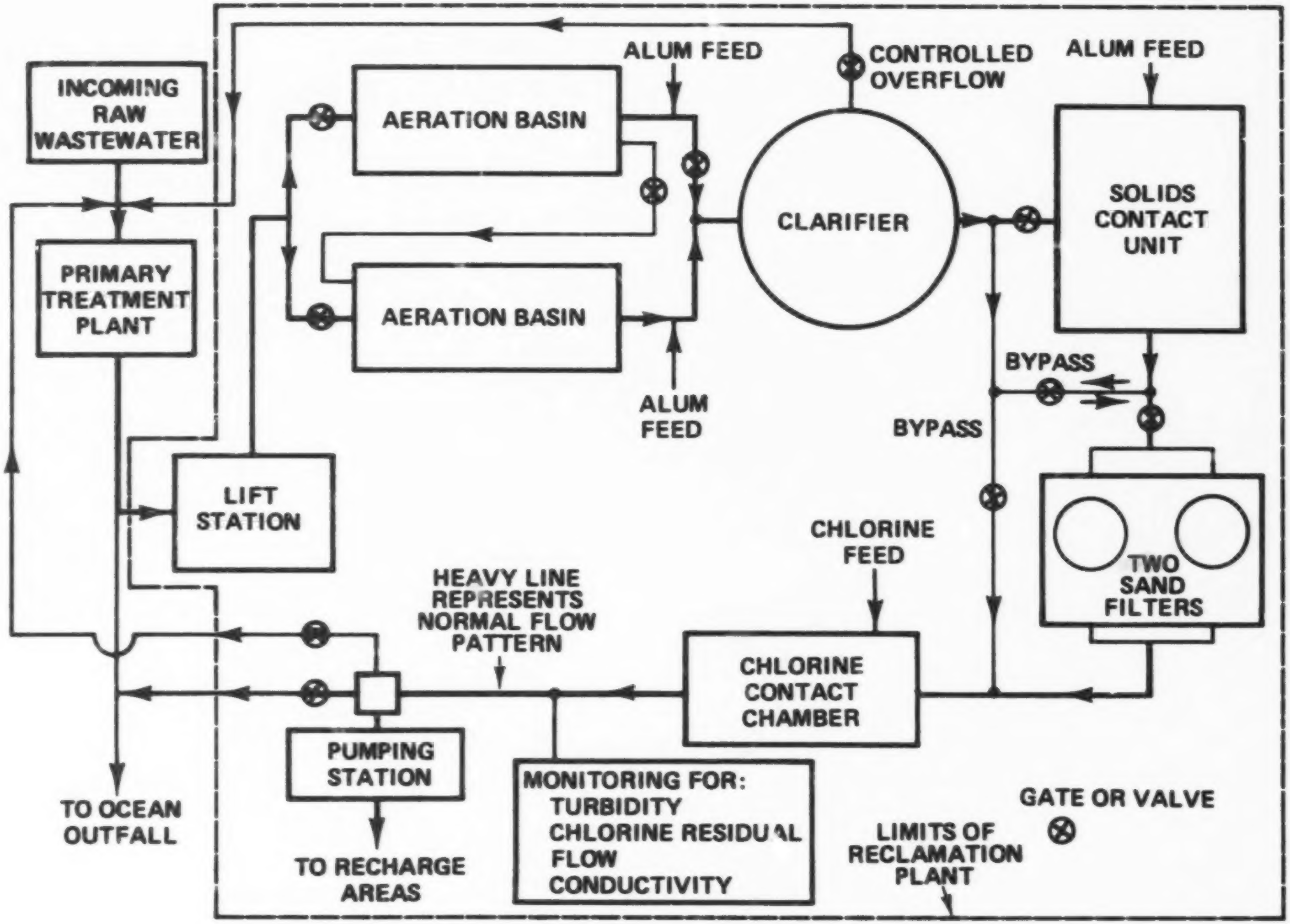
In actuality although the local government knew of the situation, steps were not taken to alleviate the potential conflict. Since the Frederiksted wastewater system was not connected to the central collection until October, 1974, there was not really a problem until then. After the connection, due to flooding damage on the island, no positive action was taken on removing the salt water until a governmental study group was formed by the governor in June, 1975, to look into the problem. It is hoped that this saltwater situation will be resolved during the fall of 1975. Until then, the project cannot use its product water for agricultural irrigation or for groundwater recharge.

Basic Design

The plant was designed to be an extended aeration activated sludge plant followed by units to permit chemical coagulation, filtration, and disinfection. A block diagram of the plant is shown in Figure 25 and an aerial photo of the facility appears in Figure 26. A list of major components with their specifications is shown in Table 3 while the major design parameters for the activated sludge section are shown in Table 4.

These parameters make it apparent that this is basically a standard extended aeration plant, but with a higher volumetric loading and aeration capacity to minimize the size of the aeration tanks. The use of a completely mixed extended aeration plant with sludge recycle gave the facility an inherent ease of operation and the ability to handle moderate shock loads. The prolonged residence time and excess aeration capacity were expected to provide the environment for the growth of nitrifying organisms which would act to convert ammonia compounds to nitrates. This, in turn, would reduce the ultimate chlorine demand at the time of disinfection.

After being aerated and continously agitated, the mixed liquor moves from the aeration tanks to a circular clarifier for solids separation, with provisions for a maximum of 100 percent sludge recycling. After clarification the flow goes to a solids contact unit (a reactor-clarifier) where chemical addition facilitates the removal



INCOMING RAW WASTEWATER
PRIMARY TREATMENT PLANT
LIFT STATION
AERATION BASIN
AERATION BASIN
ALUM FEED
ALUM FEED
CONTROLLED OVERFLOW
CLARIFIER
ALUM FEED
SOLIDS CONTACT UNIT
BYPASS
BYPASS
TWO SAND FILTERS
CHLORINE FEED
CHLORINE CONTACT CHAMBER
HEAVY LINE REPRESENTS NORMAL FLOW PATTERN
PUMPING STATION
TO OCEAN OUTFALL
TO RECHARGE AREAS
MONITORING FOR:
TURBIDITY
CHLORINE RESIDUAL
FLOW
CONDUCTIVITY
LIMITS OF RECLAMATION PLANT
GATE OR VALVE ⊗

Figure 25. Flow diagram of the AWWTP.

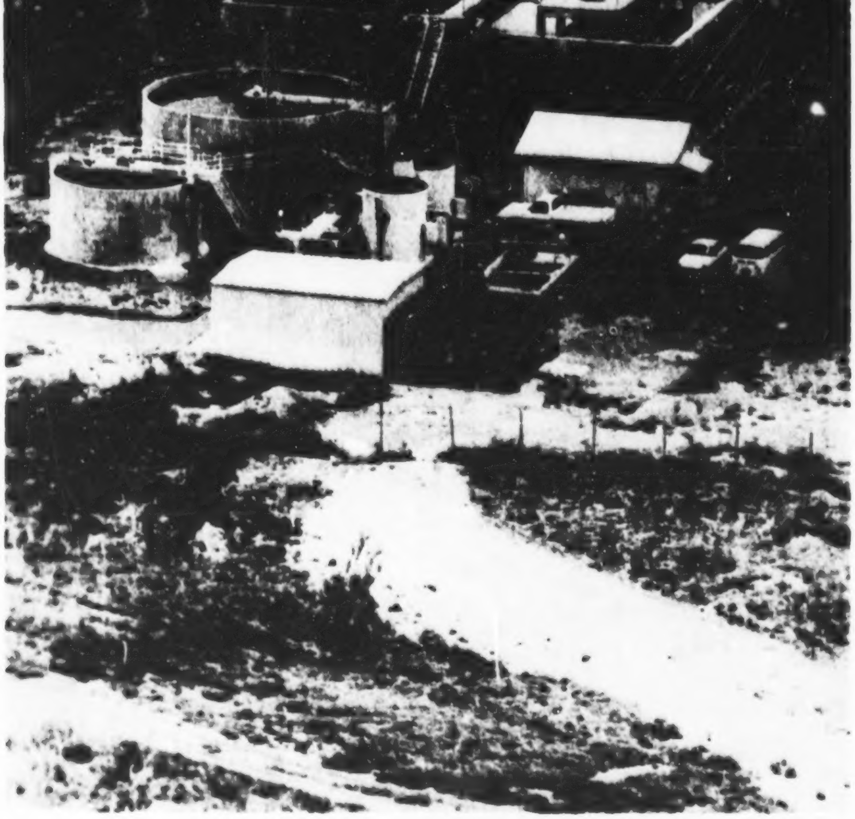


Figure 26. Aerial view of the AWWTP.

TABLE 3. EQUIPMENT USED IN THE ADVANCED WASTEWATER TREATMENT PLANT

Equipment	Quantity	Manufacturer	Additional Information
Influent sewage pumps	2	Flygt	4 in. (10 cm) CP-3126, 350 gpm at 60 ft TDH (22 l/sec at 18 m), 1,750 rpm.
Aerators, surface	4	Mixco (Lightning)	25 hp (18.6 kw), Transfer 1,800 lb (817 kg) of oxygen/day/unit.
Clarifier	1	Eimco	Type C, 35 ft (10.6 m) ID x 11 ft (7.6 m) SWD.
Sludge return pumps	2	Morris	3 in. (7.6 cm) 3HS10, 175 gpm at 25 ft TDH (11 l/sec at 7.6 m), 880 rpm.
Solids contact unit	1	Eimco	Type HRB, 22 ft (6.7 m) ID x 11 ft (3.3 m) SWD.
Chemical feed pumps	2	Wallace & Tiernan	Model A747.
Filters, mixed media	2	Jet Flo (Reyco)	Gravity, 10 ft (3 m) ID.
Backwash pump	1	Worthington	Model 12M90, 40 hp (30 kw), 950 gpm at 115 ft TDH (60 l/sec at 35 m), 1,750 rpm.
Chlorinator	1	Wallace & Tiernan	Series 91-100, 100 lb (45.4 kg)/day.
Chlorine analyzer	1	Wallace & Tiernan	Model A-767, with recorder.
Effluent pumps	2	Worthington	Model 10L22, 40 hp (30 kw), 350 gpm at 300 ft TDH (22 l/sec at 91 m), 1,750 rpm
Total effluent flow meter	1	Leopold & Stevens	Model 61R, recorder and totalizer, 90° V-notch.
Turbidity meter	1	Hach	Model 1720, Rustrak recorder.
Conductivity meter	1	Beckman	Model RQ1-7-CHIC-R1K, recorder.

TABLE 4. DESIGN AND ACTUAL PARAMETERS FOR THE BIOLOGICAL SECTION OF THE AWWTP

Parameters	Design	Actual*
Flow through the aeration tanks (mgd)	0.5	0.25 - 0.4 0.33 Estimated Average†
(cu m/day)	1,892	945 - 1,515 1,250 Estimated Average†
Aeration tank capacity (mil gal)	0.6	0.3†,#
(cu m)	2,270	1,135†,#
Detention time (hr)	29	22‡,#
Aeration tank MLSS (mg/l)	4,000 - 6,000	1,350‡
BOD (mg/l)	750	133‡
Food-to-microorganism ratio (lb BOD/lb MLSS) or (g BOD/g MLSS)	0.13	0.1‡
Rated oxygen transfer of aerators lb/hr	350	175§,#
kg/hr	160	80§,#

*Based on averages for the period January, 1974, through October, 1974.

†The plant flow meter was located at the effluent portion of the AWWTP. Since February, 1974, a portion of the influent entering the operation tanks was bypassed back to the primary plant after the clarifier, but before the flow meter. Thus the total influent could not be measured. Meters have now been installed to measure the influent flow.

‡Based on the average for the 8-month period.

§Only 2 of the plant's 4 surface aerators were used. During the majority of operation only 1 of these aerators was used at one time and hence the actual operating value would be one-half of this.

#Only one aeration tank was used during actual operations.

of remaining suspended matter including colloidal material. This chemical, aluminum sulfate (alum), is mixed in the reactor turbine section of the unit. Solids removal is by coagulation and flocculation, which results in precipitation in the clarifier section and agglomeration aiding filtration in the subsequent sand filters.

The filtration unit is composed of two gravity sand filters which operate in parallel. The design filter loading rate is approximately 2.2 gpm/sq ft (90 l/min/sq m) when both filters are in operation. Backwash water is obtained from the chlorine contact chamber and the backwashing is controlled by automatic timers.

Detention time is a minimum of 30 minutes in the chlorine contact chamber before the effluent passes over a weir to the wet well for transfer to the recharge areas by two vertical turbine pumps.

Special Design Features

Certain features were built into the AWWTP to increase its flexibility and usefulness to the project. The most important of these are discussed in the following paragraphs.

> The aeration unit is separated into two equal tanks with the water surface of one being 2 ft (0.61 m) above the water surface of the other. This permits the tanks to be operated singly, in parallel, or in series without additional pumping required.
>
> There are provisions for bypassing either the solids contact unit, the filter, or both.
>
> The effluent from the plant can be directed to either the recharge areas, the head of the primary plant, or into the ocean outfall.
>
> The plant is monitored by recording instruments to give a continuous record of the effluent turbidity, conductivity, residual chlorine, and flow.

Plant Construction

Bids were opened in January, 1972, for the construction of the AWWTP. The award was made to the Pizzagalli Corporation of South Burlington, Vermont, and construction began in April, 1972, with a contract completion date of January, 1973. The bid price was $698,400.

Although the original structural work on the project proceeded rapidly, there were delays in the fabrication and delivery of some of the proprietary devices for the plant and additional delays on the site involving subcontractors, scheduling, quality control etc. The plant was provisionally accepted in October of 1973 while final acceptance did not take place until May, 1974. Start-up began during the fall of 1973 with the plant operational by January, 1974.

Operation

The plant mode of operation was dictated by two important factors: low flows and a low BOD. In early 1974 the flows through the plant averaged less than 0.25 mgd (946 cu m/day) and the influent BODs ranged below 100 mg/l. In order to compensate for this, the AWWTP was operated using only one of the aeration tanks and the aerators were modified to run on automatic timers during only part of the day. Typically the flow from the primary plant followed a daily pattern in which the flow diminished from about 2 AM to 10 AM and then built up rapidly and continued, with oscillations, throughout the day and early evening. This changing flow pattern created problems in the solids contact unit (SCU) in maintaining a chemical sludge blanket in the reaction zone. To correct this problem, the flow pattern was modified by splitting the clarifier effluent and returning a portion of the high flows back to the primary plant. This return flow was ultimately recycled to the AWWTP but delayed in time. This had the effect of clipping the peak flows and augmenting the low flows through the solids contact unit. This steadier flow improved the SCU performance remarkably, but at the sacrifice of a lower influent BOD, by dilution and a reduced production level from the plant.

Successful operation of the plant was very sensitive to the food to microorganism ratio as reflected in the organic loading parameter, pounds of BOD applied per pound of solids under aeration (g/g).

A comparison of the actual average loading factors with the design parameters is presented in Table 4. This shows the overall organic loading for the operating period remaining very close to the design factor of 0.13 although the operational data for the plant, as displayed in Table 5 and the Appendix, shows changes in both influent organic concentration and the mixed liquor suspended solids (MLSS) concentration in the aeration tank. Operational experience proved that the plant operated best at this loading factor and performance suffered considerably with deviation from this level, especially with a lower loading factor. Thus careful attention had to be paid to the amount of MLSS in the aeration tank compared to the influent BOD. Excess solids were pumped to the unused aeration tank which acted both as a sludge storage facility and an oxidation pond. This method of sludge handling provided a safeguard for plant operation, allowing the addition of microorganisms to the plant at times when, due to upsets, improper operation, or toxic materials, the sludge concentration was reduced in the aeration tank.

TABLE 5. OPERATING DATA FOR THE AWWTP (AVERAGE VALUES FOR THE PERIOD JANUARY TO OCTOBER, 1974)

Parameter		Influent	Effluent	Aeration Tank
BOD	mg/l	113	12	--
COD	mg/l	206	31	--
Total P	mg/l	12.3	9.0	--
NO_3-N	mg/l	0.6	12.9	--
NH_3-N	mg/l	22.6	6.8	--
CO_3	mg/l as $CaCO_3$	0	0	--
HCO_3	mg/l as $CaCO_3$	318	123	--
Total Hardness	mg/l as $CaCO_3$	289	--	--
Ca	mg/l as $CaCO_3$	114	--	--
Mg	mg/l as $CaCO_3$	172	--	--
Chlorides	mg/l	456	--	--
Conductivity	μmhos/cm^2 at 25° C	1,778	--	--
pH		7.4	6.7	--
Turbidity	FTU	--	1.3	--
MLSS	mg/l	--	--	1,351
SVI	ml/g	--	--	75

Nitrification did occur within the secondary units, as shown by the ammonia and nitrate data in Table 5. But this process, especially reinforced by excess aeration and possibly other factors, made solids separation difficult in the clarifier. The amount of aeration was always a compromise between enough to keep the aeration tanks mixed and hold a reasonable dissolved oxygen content, but not too much to induce bulking and subsequent excess solids carry-over in the clarifier.

The modification of the plant to permit the addition of alum to the effluent of the aeration tanks improved settling characteristics considerably. A dose rate of from 14 mg/l to 25 mg/l was found to be effective.

While nitrification did reduce the chlorine demand during disinfection, it also created a problem by setting the stage for denitrification in the clarifier. This problem is noted by Sawyer (1967) and Busch (1971) who suggest the expeditious removal of the sludge before it can be buoyed to the surface by entrapped or attached nitrogen gas bubbles. This problem would generally occur in the early morning hours when the flow from the primary plant was reduced. This often permitted the sludge underflow in the clarifier to jam in the telescope valve, if the latter was not set exactly right, causing the sludge to start to build up at the bottom of the tank. This soon was buoyed up and drastically increased the solids loading to the solids contact unit and the filters, generally clogging the latter. Continuation of this process for any length of time usually resulted in a serious reduction of MLSS and, in general, unsatisfactory plant performance.

In operating the solids contact unit, an alum dose of between 20 mg/l and 35 mg/l was found to produce a good sludge blanket. Automatic sludge withdrawal was adjusted to keep the top of the sludge blanket at least 5 ft (1.5 m) from the surface.

Alum was used as it was relatively inexpensive, functioned without pH adjustments, was simple in operation, and worked. Some experimentation was made using commercial polymers but the results did not justify the extra cost and problems.

While alum worked quite well during the project's operational period, it may be that in the future when the mineral content of the wastewater changes due to shifts in the water source to desalinized water, other coagulants and filter aids will need to be employed.

Not only does alum react with the bicarbonate in the wastewater as follows:

$$Al_2(SO_4)_3 + 6HCO_3^{-1} \rightarrow 2Al(OH)_3 + 3SO_4^{-2} + 6CO_2$$

to form a voluminous, gelatinous floc to aid in clarification, but it also combines with phosphates in this reaction:

$$Al_2(SO_4)_3 + 2PO_4^{-3} \rightarrow 2AlPO_4 + 3SO_4^{-2}$$

Culp (1971, p. 27) mentions that the "two reactions compete for aluminum ions. At pH values above 6.3, the phosphate removal mechanism is either by incorporation in a complex with aluminum or by adsorption on aluminum hydroxide floc."

The pH of the wastewater at the point of alum application was about 7.2. The pH was reduced in the AWWTP by approximately 0.6 units due to alum addition and disinfection. Total phosphorus reduction did occur but the removal rate was not consistent. Removals ranged from about 10 to 60 percent within the plant. Phosphorus removal was not a goal of plant design and only occurred as a by-product of clarification. Phosphorus was expected to cause no problems in recharging and would be removed in the upper soil layers by the clays and silts in the area.

Disinfection was accomplished by the use of gas chlorination. Originally 150-lb (68 kg) cylinders were used to supply the gas but early in the project this system was converted to 1-ton (908 kg) cylinders. This reduced the cost of the chlorine from approximately \$0.50/lb (\$0.23/kg) to about \$0.25/lb (\$0.11/kg). Dosage varied with effluent quality but generally ranged from 20 to 30 mg/l. This was more than was actually needed since a steady rate of chlorine feed was used to maintain the minimum FCR desired at all flow levels. Thus the selected rate chlorinated the high flows and organic surges at the proper FCR and overchlorinated during the low flows. A programmed proportional feeder could reduce the usage of chlorine considerably.

The results of disinfection were excellent, with a reduction of coliform bacteria from a magnitude of 10^7 colonies/100 ml in the AWWTP influent to a value of 0 and occasionally 1 colony/100 ml in the effluent.

Plant Production

When the interim report for this project was published in October, 1973 (Black, Crow and Eidsness, Inc.), it predicted that it would only be possible to produce a maximum of 750,000 gal/wk (2,839 cu m/wk). This was attributed to the expected low wastewater flows to the primary plant, the pattern of pumping associated with the primary plant, and the lack of personnel to man the AWWTP on a 24-hour basis.

This situation would have been substantially improved with the addition of the wastewater flow from Frederiksted, but it was decided to continue ahead with the project without waiting for completion of that phase of the wastewater collection system. As it was, work was not completed on the crucial Frederiksted pumping station, whose operation about doubled the flow to the primary plant, until October, 1974.

However, by making certain modifications to the basic plant design and operations schedule, it was possible to exceed the estimated maximum production level; and by the time the recharge work was suspended, in October, 1974, the plant was averaging over 1 mil gal/wk (3,785 cu m/wk) and had boosted its maximum daily production to about 300,000 gpd (1,135 cu m/day). This represents effluent actually delivered to the recharge areas. Actual production in sections of the plant was higher.

A bar graph showing the actual weekly production and delivery of reclaimed wastewater to the recharge area is shown in Figure 27. These data exclude water produced and not pumped to the recharge area and water used for backwashing.

Delivery of water to the recharge areas was halted if the guidelines for turbidity or free chlorine residual were exceeded or if the chloride content exceeded 500 mg/l to 550 mg/l. Generally the plant operated at a turbidity level of about 1.5 FTU and a FCR of 4 mg/l.

Operational Problems

Aside from the low flows to the plant,power input problems plagued the plant throughout its operation. Failures in the island's power distribution system are common. The manner in which the power would be cut off to the plant would often cause the control circuits to register an overload and to open their automatic circuit breakers, which required manual resetting. If this occurred on weekends or evenings when the plant was not manned, then the plant would not function properly and production was lost.

Difficulties with various pumps posed the next most troublesome problem in the operation of the plant. The reliability of the pumps was probably affected by their remaining idle for a long period of time when the plant was delayed in completion and then operating under a salty tropical condition. More production was lost due to pump difficulties than from any other mechanical cause. Initial troubles centered around the submersible pumps on the influent station. These initially had two manufacturing defects which took considerable time to finally locate. Then one of the pumps had to be completely overhauled due to a seal failure. However for the past 18 months they have been operating without problems.

The plant water pump has burnt out once and lost its impeller on another occasion. The vertical turbine effluent pumps had a series

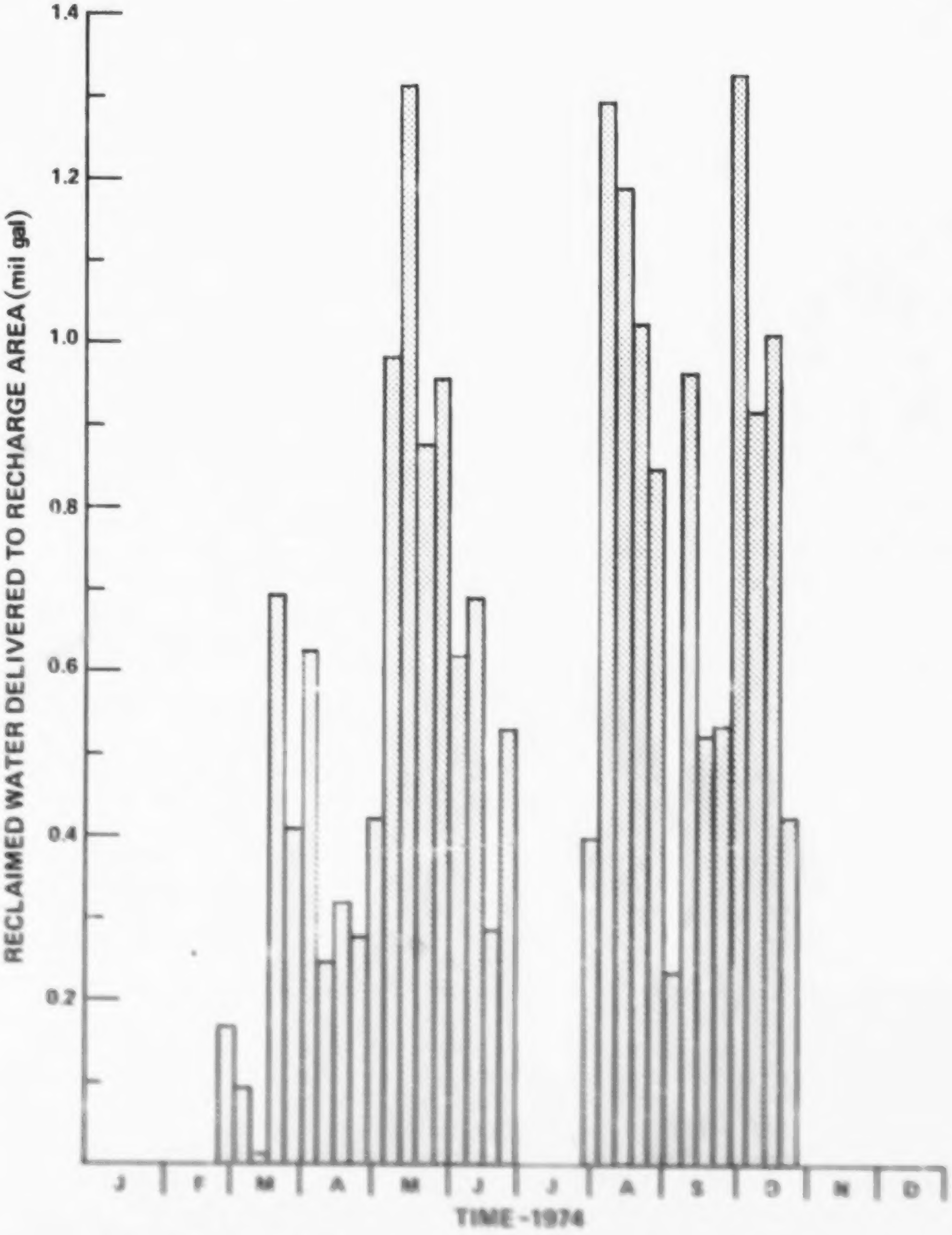


Figure 27. AWWTP production utilized for artificial groundwater recharging.

of problems during the summer of 1974. The motor on one of the pumps shorted out and required rewinding, and the pump assembly on the other required a complete overhaul. Since these incidents occurred within a few days of each other in July, it adversely affected the plant's ability to transfer treated effluent to the recharge area for about 5 weeks until repairs were effected. The distance from the mainland and the difficulty in obtaining spare parts and service turns a small incident like this into a major problem.

An algal problem was experienced in the clarifier, solids contact unit, filters, and chlorine contact chamber. In the clarifier the algae formed on the effluent trough and baffle. This was handled by scrubbing down the affected area twice a week before the algae built up to an unmanageable degree. The problem was severe in the solids contact unit and the final solution was to cover the unit with an opaque polypropylene fabric which was custom-made by a local sailmaker. This has worked excellently and has solved the difficulty. The algal buildup in the filter was controlled by the chlorine in the backwash water and a plywood cover over the splitter box.

The direct sunlight on the chlorine contact chamber not only created an algal problem but it caused a higher chlorine demand during the daylight hours. Initially a temporary opaque plastic cover was placed over the chamber but this was later replaced by the construction of a 50 x 20 ft (15 x 6 m) steel building over the chamber. This not only served the purpose of covering the chamber but it provided extra storage room for chemicals (alum) and tools plus an office and shower area for the operators.

Plant Expansion

The present capacity of the AWWTP is adequate to permit the artificial recharge and recovery of sufficient groundwater to economically justify its operation. If there is a viable market for additional reclaimed wastewater and if there is a reliable longterm supply of wastewater of a quantity that merits treatment, then the expansion of the AWWTP should be considered.

However extensive capital outlays should not be made on expansion until a reasonable plan has been agreed to for the disposition of the high chloride wastewater from both the Frederiksted and the Christiansted areas.

The AWWTP has the capability for inexpensive expansion of capacity built into many of the units, so that outright duplication of the units would not be necessary. The following is a discussion of each major unit operation as it applies to future plant expansion.

Influent Pumping. This is an item that needs correction immediately. The influent to the AWWTP is erratic due to the diurnal pattern of flows in the interceptors and the nature of the high capacity pumps used in the primary plant lift station. With their present installation the flat rate 350 gpm (22 l/sec), AWWTP influent pumps either do not get enough to pump or cannot handle all that is available from the ocean outfall line.

It is suggested that the present AWWTP lift station be abandoned and the pumps be relocated at the effluent end of the primary clarification basins. These basins will act as large equalization tanks permitting the pumps to deliver a continuous flow to the AWWTP.

The proper location of the pumps will allow the rakes to function unimpaired, although the surface skimmers will be inoperative while the level of the tank is below the effluent weir. Certain adverse currents may be induced during low flow operations; but since the product will be receiving additional treatment in the AWWTP, it should not be a great disadvantage.

It is suggested that 8-in. (20 cm) cast or ductile iron pipe be used from the pumps to the AWWTP along with throttling valves to adjust the head. This will reduce the friction head over the longer distance so that the original pumps can still be used. It will also provide capacity so that the pumps can be operated at higher rates when desired. When in dual, parallel operation using the new pipeline, it is believed that the present pumps will be able to deliver up to 550 gpm (35 l/sec).

The installation of this change now could probably increase the reliable output of the AWWTP by about 0.1 mgd (378 cu m/day). The need to bypass and return a portion of the flow in the secondary clarifier would be largely eliminated. A smooth flow, steady organic loading, and efficient chemical addition could be maintained 24 hours per day.

Aeration. The aeration section of the plant is overdesigned for the wastewater now being processed; and by operating both aeration tanks, there should be little problem in handling up to 700 gpm (44 l/sec) both from a hydraulic and oxygen transfer standpoint. This is assuming that the wastewater characteristics do not change in the future.

Clarification. The design loading is about 540 gpd/sq ft (22 cu m/day/sq m) of surface area in the clarifier. However with the use of coagulants such as alum and the proper operation of the aeration tank, this loading can probably be exceeded without problems. The higher level must be determined by actual experimentation since it will depend on the makeup of the wastewater and the selection and dosage of coagulants used.

During plant operations extended trial runs were made adding alum to the effluent from the aeration tank to improve solids separation in the clarifier. This enabled plant personnel to bypass the solids contact unit (SCU) and transfer the clarifier effluent directly to the filters. This eliminates the SCU from use and it could be utilized, with some modifications, as an additional clarifier to work in parallel with the present one. Keeping the same design surface loading rate, this would allow the clarification of an additional 0.2 mgd (757 cu m/day) of mixed liquor suspended solids. However there are some disadvantages to keep in mind.

The SCU acts as a backup for the clarifier. If the clarifier malfunctions and permits solids carry-over, the solids are usually handled in the SCU. Without the SCU the solids would rapidly clog the filter.

The second major disadvantage is that there are no provisions for surface skimming nor underflow solids return to the aeration tank from the SCU.

Filtration. It is doubtful that this unit can increase its production capacity. It is suggested that if additional filtration capacity is needed, another filter unit capable of handling at least 350 gpm (22 l/sec) be purchased and installed.

Effluent Pumps. To increase production it would be necessary to purchase new pumps with a higher capacity. These could be installed in the same location as the old pumps. These should be selected and equipped with throttling valves so that the rate of discharge can be matched to the production level of the plant. This will prevent the wet well from being emptied too rapidly and thus reducing the cycling of the pumps. The old pumps could be utilized, at a later time, at a booster station to transfer reclaimed water from a storage facility at the Department of Agriculture's Lower Love facility to various points for irrigation purposes.

Expansion Plan. It is recommended the expansion of plant capacity be carried out in 3 phases. After each phase, performance of the system should be reevaluated and modifications made, as necessary to the next phase. These phases, along with a generalized cost estimate are discussed in the following paragraphs.

Phase 1 - 0.5 mgd (1,892 cu m/day) - Move the influent pumps to the effluent end of the primary settling tanks. Construct the line to transfer the wastewater from the primary plant to the aeration tank. Install throttle valves on the influent and effluent pumps. Expand the recharge area. Estimated cost $30,000.

It is suggested that these improvements be made as soon as possible.

Phase 2 - 0.75 mgd (2,725 cu m/day) - Install an additional 350 gpm (22 l/sec) gravity filter. If the clarifier cannot handle the new load, then repipe the solids contact unit in parallel. Install effluent pumps with a capacity of 700 gpm (44 l/sec). Expand recharge areas. Estimated cost $70,000.

Phase 3 - 1 mgd (3,785 cu m/day) - Install an additional clarifier, new influent pumps, and expand the recharge area. Make general plant improvements to handle higher loading. Estimated cost $140,000.

RECHARGE AREAS

The development of the recharge facilities took place in stages during the construction and operational phases of the project. The initial facilities developed covered those types of surface recharge methods which appeared to offer the most promise as far as recharge in the existing soil strata was concerned. As noted previously, it was expected that the AWWTP would produce about 750,000 gal/wk (2,840 cu m/wk) in the period following start-up and the recharge facilities were sized to handle this capacity.

As operations continued and information was collected, the data were evaluated and the facilities were modified, expanded, or phased out as the situation dictated. The original recharge facilities consisted of spreading basins, spray irrigation, and spreading in a dry streambed. All of these facilities were built with flexibility to permit modification to ensure maximum efficiency. Although the effluent from the AWWTP was conveyed to the recharge areas in a permanent ductile iron force main, the final portion of the piping from the force main to the basins, etc., employed portable aluminum and PVC pipe so that changes could be readily made by project personnel with a minimum of effort and expense.

As discussed in the section on preliminary investigations, recharge was planned to take place in two separate areas, Golden Grove and Negro Bay, which were geologically different but located very close to each other and hence easily served by the same force main and storage tank. Golden Grove was to be the major facility, with the Negro Bay site to be used for secondary experimentation.

As part of the final selection and location process for the recharge sites, a series of wells were drilled in the two areas to further define the geological strata. The logs of these wells and a chart of the soil borings appear in the Appendix and the well locations are shown on Figure 6.

Three of these nine wells, PW-1, PW-2, and PW-4, were transferred to the Public Works Department (PWD), which activated them for use in its potable water system. At the time of drilling and initial pump tests these wells had a demonstrated aggregate total capacity of about 100 gpm (6.31 l/sec). This addition of approximately 140,000 gpd (530 cu m/day) to the potable water system was meant to aid the PWD in building up its freshwater reserves so that it would be able to switch the saltwater flushing system in Frederiksted to fresh water when the town's wastewater was diverted to the new primary treatment plant at Bethlehem Middle Works.

However as drought conditions persisted on the island, the yield of the wells decreased to approximately 60 percent of their initial rates. Still, this would be sufficient production to allow substitution of potable water for salt water in Frederiksted where the saltwater usage is approximately 75,000 to 80,000 gpd (284 to 302 cu m/day).

The active project well in Negro Bay, PW-2, was located where it should not, due to the geology of the area, be affected by the recharging operations at the Negro Bay site. However the two wells in Golden Grove, PW-1 and PW-4, should be affected to some degree by the recharge operations in that area. PW-1 was located approximately 200 ft (61 m) from the edge of the nearest spreading basin, while PW-4 was about 300 ft (91 m) from the same basin. Although the wells were hydrologically upstream of the recharge site, they were expected to extract a small diluted portion of the artificially recharged water. The recharging was also expected to increase the yields of these wells since water was being added to one of the aquifers being pumped. This increase, however, would not necessarily be directly and entirely from the recharged water but most probably would be due to a combination of recharge flows and impounded aquifer flows resulting from the damming up of the aquifer by the artificial mound created at the recharge site immediately downstream.

The recharge areas were developed and constructed within the project by renting heavy equipment for the earth-moving portions and performing the minor work remaining using project personnel. The development and operation of the two areas are described in the following discussion.

Golden Grove Recharge Area

Description. The Golden Grove recharge area consists of six spreading basins and six small check dams in the adjacent riverbed. A sketch of the facility is shown in Figure 28 and an aerial photograph showing a portion of the basins is seen in Figure 29.

The six spreading basins were constructed with a total bottom area of about 45,000 sq ft (4,180 sq m). During construction the upper layer of the soil was removed in each case to expose the more porous lower horizons. Due to the extremely clayey soil between the

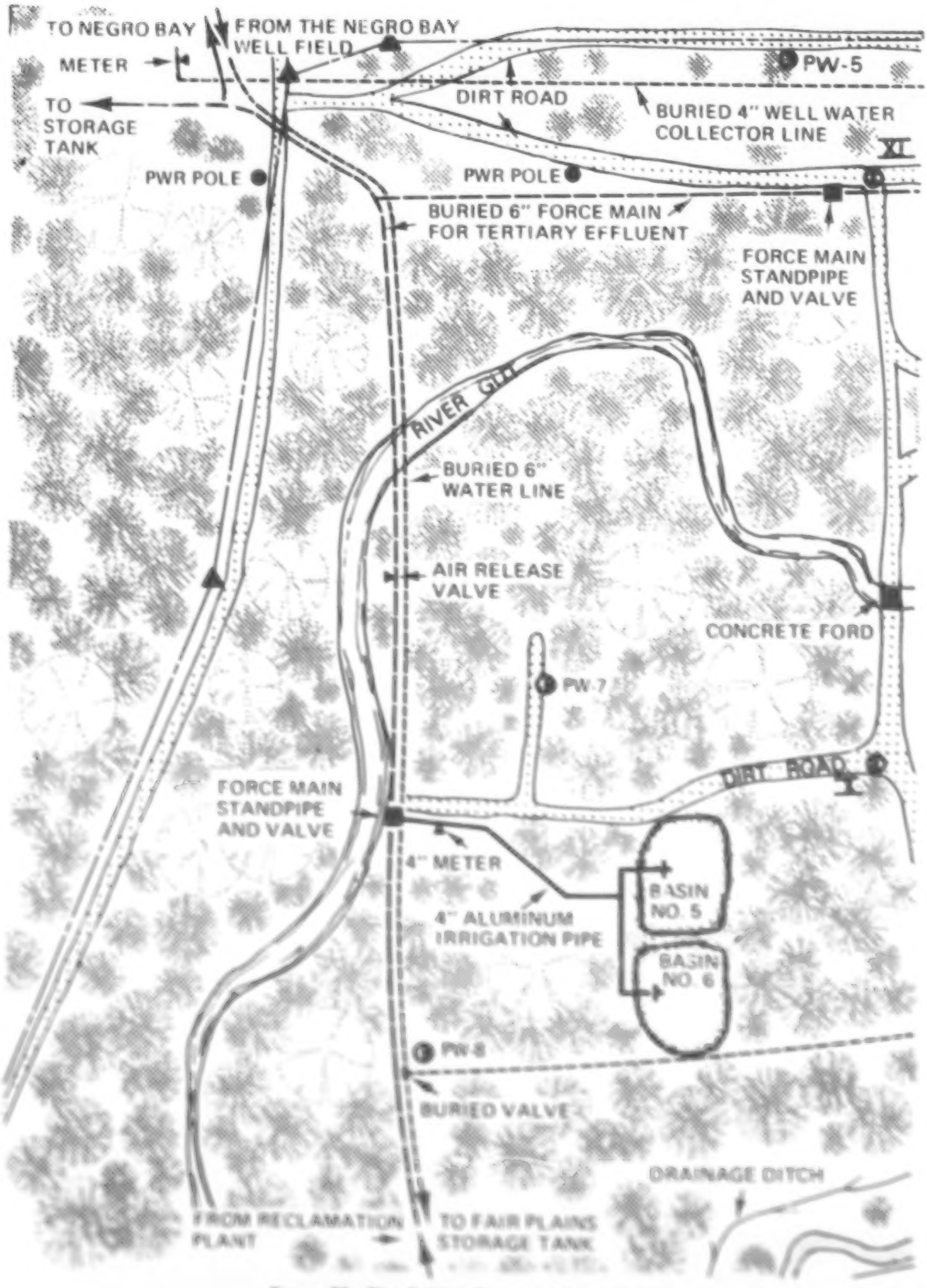

TO NEGRO BAY
FROM THE NEGRO BAY WELL FIELD
METER
TO STORAGE TANK
PW-5
DIRT ROAD
BURIED 4" WELL WATER COLLECTOR LINE
XI
PWR POLE
PWR POLE
BURIED 6" FORCE MAIN FOR TERTIARY EFFLUENT
FORCE MAIN STANDPIPE AND VALVE
RIVER GUT
BURIED 6" WATER LINE
AIR RELEASE VALVE
CONCRETE FORD
PW-7
DIRT ROAD
X
FORCE MAIN STANDPIPE AND VALVE
4" METER
BASIN NO. 5
4" ALUMINUM IRRIGATION PIPE
BASIN NO. 6
PW-8
BURIED VALVE
DRAINAGE DITCH
FROM RECLAMATION PLANT
TO FAIR PLAINS STORAGE TANK

Figure 28. The Golden Grove recharge area.

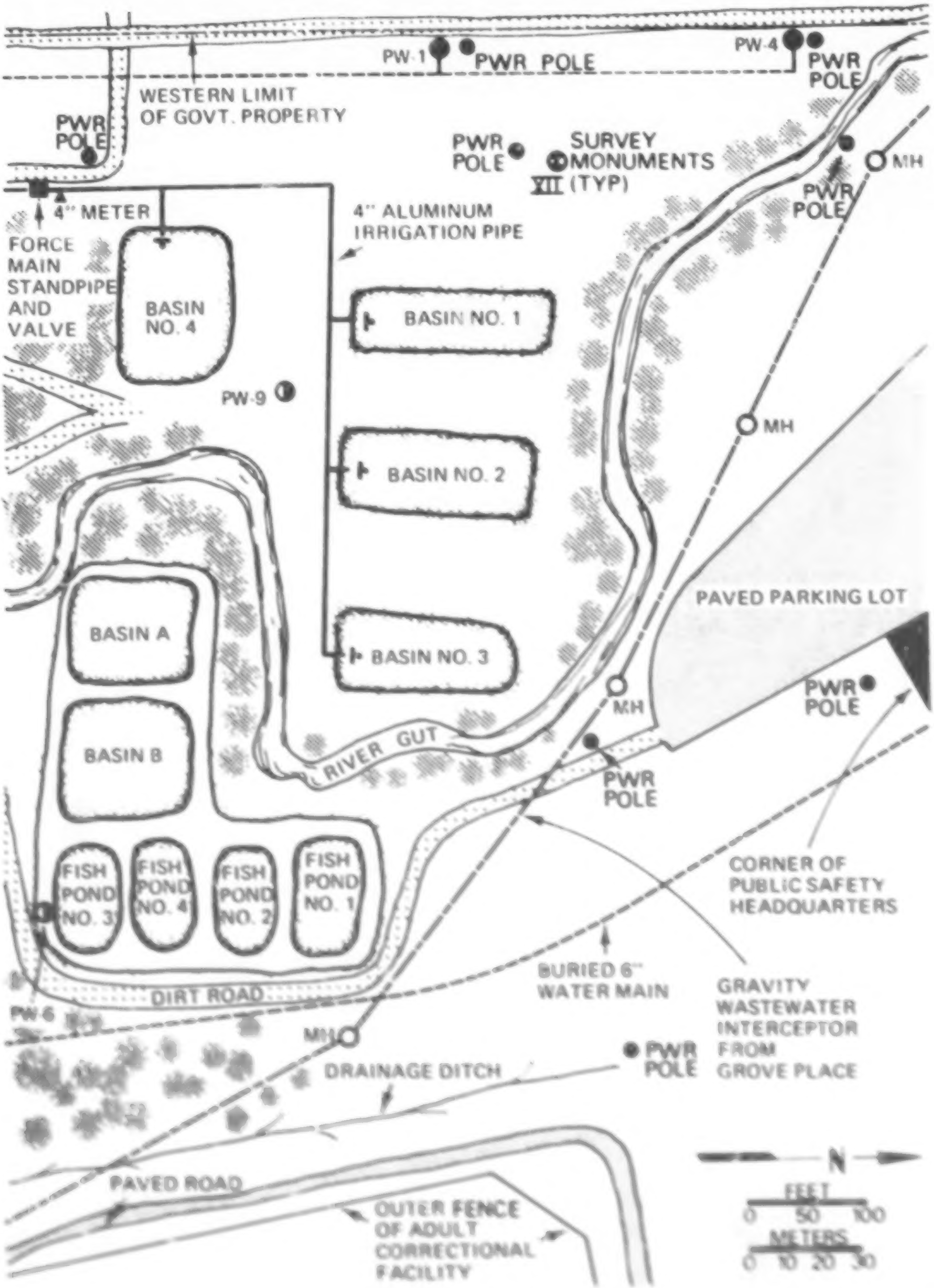

PW-1
PWR POLE
PW-4
PWR POLE
WESTERN LIMIT OF GOVT. PROPERTY
PWR POLE
PWR POLE
SURVEY MONUMENTS XIII (TYP)
MH
PWR POLE
4" METER
4" ALUMINUM IRRIGATION PIPE
FORCE MAIN STANDPIPE AND VALVE
BASIN NO. 4
BASIN NO. 1
PW-9
MH
BASIN NO. 2
PAVED PARKING LOT
BASIN A
BASIN NO. 3
MH
PWR POLE
BASIN B
RIVER GUT
PWR POLE
FISH POND NO. 3
FISH POND NO. 4
FISH POND NO. 2
FISH POND NO. 1
CORNER OF PUBLIC SAFETY HEADQUARTERS
BURIED 6" WATER MAIN
GRAVITY WASTEWATER INTERCEPTOR FROM GROVE PLACE
DIRT ROAD
PW-6
MH
PWR POLE
DRAINAGE DITCH
N
FEET
0 50 100
METERS
0 10 20 30
PAVED ROAD
OUTER FENCE OF ADULT CORRECTIONAL FACILITY

Figure 29. (Extended)

Figure 29. Aerial view of the Golden Grove recharge area

upper aquifer and the one immediately below it, the upper one acts as a conduit to move the new water horizontally with minimal leakage between the two.

Bermuda grass was developed in the recharge basins and surrounding areas. This grass was selected as it is tolerant to a high level of dissolved solids and is quite resistant to dry periods, prolonged flooding, and heavy traffic. The grass aids in stabilizing the soil, reducing erosion while creating root channels to encourage infiltration and percolation. Due to normal uptake and metabolism, a portion of the nutrients contained in the recharged water is incorporated in the plant material. This low grass is easily cut, harvested, and mechanically removed from the recharge area. This effectively removes some of the nutrients from the system. No definitive studies were undertaken on the nutrient uptake by the Bermuda grass but the grass grew luxuriantly during a time of severe drought on the island.

Water was brought to each spreading basin by a 4-in. (10 cm) diameter aluminum irrigation pipe. The water was discharged into the basin by impinging it upon a splash block and a pile of large stones. This dissipated the energy in the water so that it could enter the basin without eroding the bottom.

Each pond was first tested for a short period to ascertain its relative ability for infiltration and percolation. After this, two ponds were selected to determine how long the wet cycle of operation could be extended without a noticeable drop in infiltration efficiency.

During recharging operations the selected basin, or basins, were filled to a height of 3 to 3.5 ft (0.9 to 1.1 m). Then the flow to the pond was adjusted to maintain the same water depth. This meant that the water was entering the pond at the same rate that it was being lost by infiltration and evapotranspiration. It proved relatively easy, in practice, to hold the depth to within 0.5 ft (0.15 m) through the use of adjustable valves at the force main standpipes. The results of the operation are outlined in the section on results and discussion.

The work using the check dams in Golden Grove was scheduled to begin in November, 1974. Unfortunately recharge operations were suspended due to the high TDS of the wastewater and the floods during that month; therefore no data were collected on that phase of the project.

Design Considerations. One of the best guides to the design and operation of a groundwater recharge system using wastewater effluent is a report entitled "Soil Mantle as a Wastewater Treatment System" by McGauhey and Krone (1967). This was based on considerable experience with septic tank studies and was broadened to include other soil-oriented treatment systems involving wastewater. Aside from an extensive literature review and discussion of the the theoretical aspects of the subject, the authors present some recommendations for the design and operation of an engineered soil system. As part of these recommendations they developed eight criteria for optimizing such a system. These criteria from the report (McGauhey, 1967, p. 144) are quoted below; and following each one is a discussion of its application to the system constructed in Golden Grove on St. Croix.

In reviewing these criteria and subsequent discussions it must be kept in mind that they were developed for a soil-aquifer system which was meant to act as a treatment process for wastewater. In the St. Croix project the soil-aquifer system is meant to be a treatment process only in the sense of a polishing of the extensive processing that has already taken place in the AWWTP. The system also acts as a safety barrier against any occasional deficiencies in the treatment process. Hence it is expected that the soil system will reduce nutrients and remove most organics, bacteria, and viruses,but it is not to be expected to bear the brunt of the oxidation and filtration processes that a system using settled wastewater or septic tank effluent might experience.

"Criterion 1: The infiltrative surface should be no less permeable than any undisturbed parallel plane within the system."

As part of the construction of the basins the upper, less permeable, layer was removed to expose a more permeable soil horizon. Soil borings in the area indicate that permeability does not decrease below the newly exposed horizon before the upper aquifer is reached.

"Criterion 2: The soil surface should be managed in such a manner as to disperse clogging material."

One of the suggestions made by McGauhey and Krone was to grow vegetation on the areas to provide root channels and expand the soil. This was done using Bermuda grass which additionally stabilized the banks of the basins to permit foot traffic and incorporated a portion of the applied nutrients in their plant material for removal by harvesting.

"Criterion 3: There should be no abrupt change in particle size between coarse trench fill or surface cover material and soil at the infiltrative surface."

Since the existing soil structure is the infiltrative surface, this is no problem as no larger material, such as gravel, is applied to this surface.

"Criterion 4: The infiltrative system should provide a maximum of sidewall surface and a minimum of bottom surface."

The use of a basin design entirely violates this criterion. The cost of construction, ease of maintenance, and simplicity in operation were deciding factors in selecting spreading basins over trenches. Additionally the use of vegetation for dispersing any clogging material (Criterion 2) and nutrient uptake can be maximized with the basin configuration.

"Criterion 5: Continuous inundation of the infiltrative surface must be avoided."

By using a system design, such as the one in Golden Grove, containing many basins; the flow can be diverted to any of the basins, allowing some to be utilized while others are allowed to dry out. Successful management of the facility depends on having sufficient basin area so as to provide for alternative loading and drying cycles during operation. The area required in the future has been reevaluated on the basis of the results obtained and is discussed under the section on monitoring activities.

"Criterion 6: Aerobic conditions should be maintained in the soil system."

This is to promote aerobic metabolism by the soil biota to prevent the buildup of undesired anaerobic by-products such as clogging slimes or taste and odor-causing compounds. This can be maintained in several ways. The first is to use alternate loading cycles, wet and dry, in the operation of the spreading basins. Another is to remove the water accumulating in and above the aquifer under the spreading basin as rapidly as possible so as to prevent the groundwater mound from building up until it reaches the bottom of the basin. The section on recommendations for future development covers this situation.

"Criterion 7: The entire infiltrative surface should be loaded uniformly and simultaneously."

Since the bottom area of the spreading basins is the primary infiltrative surface, it will be loaded rather uniformly as the bottoms are relatively level. The sidewalls, however, are loaded differentially, but they do not contribute as much to the total recharge effort.

"Criterion 8: The amount of suspended solids and nutrients in the applied water should be minimized."

The design of the treatment process for this project was oriented towards a high reduction of suspended solids and organic material. The problem of a mat forming on the surface of the soil and clogging the pores did not manifest itself to any noticeable extent in the project during normal operations.

Nutrients were not fully removed in processing at the AWWTP, with ammonia generally converted to the nitrate form and the phosphates only partially removed. Undoubtably the growing and harvesting of Bermuda grass in the spreading basins aided in the removal of additional nutrients while the soil itself is capable of handling phosphate removal.

Negro Bay Recharge Area

Description. In the Negro Bay area two types of recharge methods were tested: spreading basins and spray irrigation. A sketch of the facilities is shown in Figure 30. The spray irrigation portion consisted of a gently sloping (0.031) field 250 ft by 250 ft (76 m by 76 m). The water was transferred from the permanent standpipe to the field by 4-in. (10 cm) aluminum irrigation pipe. In the spray area grids containing 8 spray heads each were set in the field. The feed in the grid loops was by 2-in. (5 cm) PVC pipe. The spray heads were Rainbird 30 B-TNT with an 11/64 x 3/32 nozzle that was rated for a 92-ft (28 m) diameter circular spray pattern at 40 psi (258 kg/sq cm) with an individual feed of about 7 gpm (0.44 l/sec). These spray heads were placed on 2.5-ft (76 cm) risers at 60 ft x 60 ft (18 m x 18 m) spacing. The actual rate of surface loading was about 2 gpd/sq ft (0.08 cu m/day/sq m).

The normal mode of operation was to run the entire system 3.5 to 13 hours at a time with the total loading ranging from 0.3 to 1.1 gal/sq ft (0.012 to 0.044 cu m/sq m). Higher loading than this caused surface runoff and erosion of the soil.

The entire area was seeded with Bermuda grass which, due to the poor soils in the area, did not fill out as thickly as it did in the Golden Grove spreading basins.

The results of the tests were not encouraging. Water did not build up in the various piezometric tubes installed in the area. If the spraying time or amount of water applied at a single time was increased, runoff occurred. The rate of application was far below that of the ponds. What apparently occurred is that the soil moisture in the upper layer was increased during spraying periods; but in the periods between spraying, the water was removed by evapotranspiration aided by the capillary nature of the marly soil which acted as a wick for the water incorporated in the soil. To decrease erosion a better vegetative cover could have been developed by leaving more of the clayey soil on the surface. However this would also act as a further barrier to the infiltration of water applied by spraying.

The two spreading basins in the Negro Bay section were run on an alternating wet and dry cycle. Each pond has an average bottom area of about 2,500 sq ft (232 sq m). The ponds are built on a slight slope so that the water depth is limited by the downslope side. The

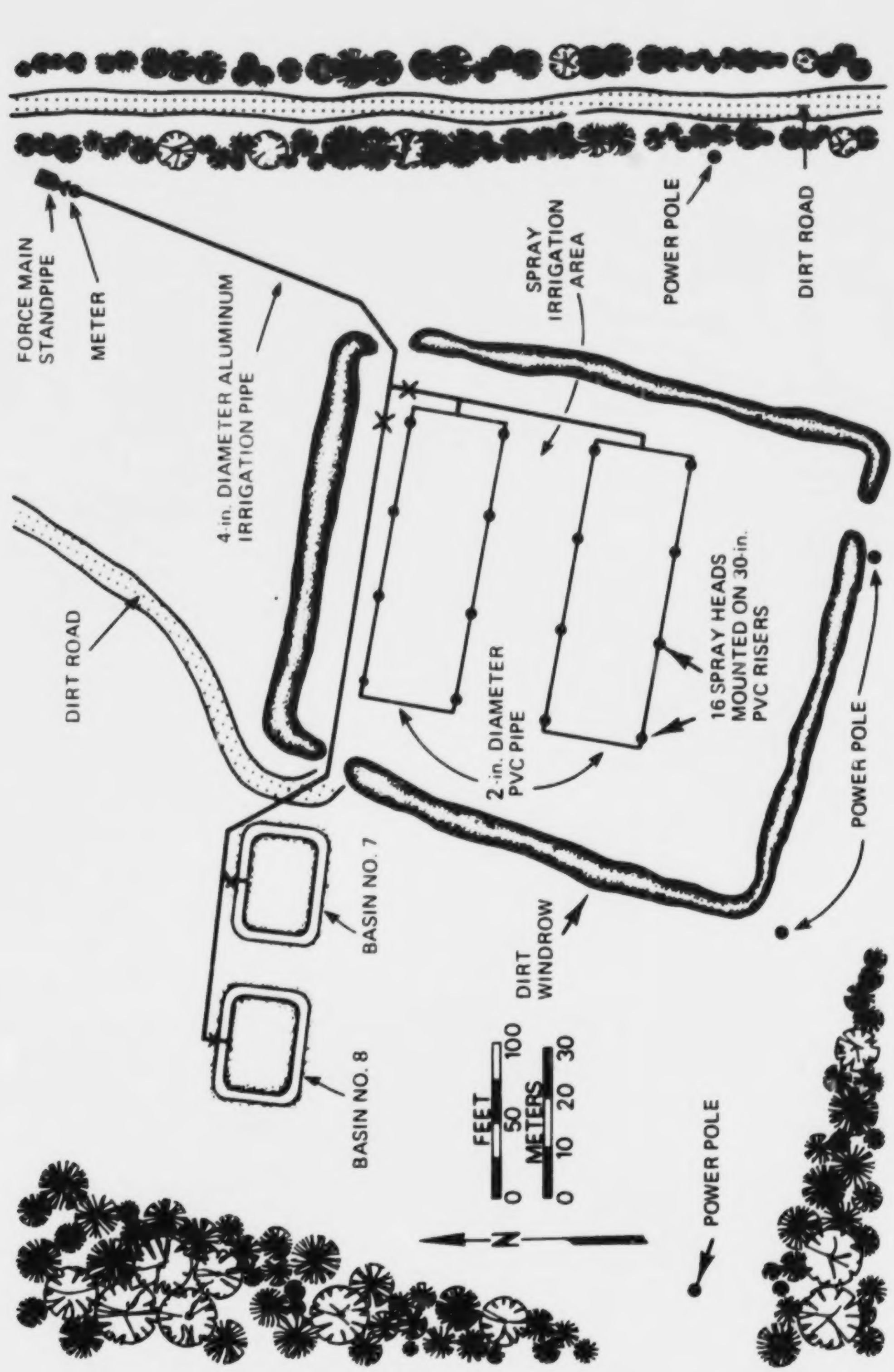

FORCE MAIN STANDPIPE
METER
4-in. DIAMETER ALUMINUM IRRIGATION PIPE
SPRAY IRRIGATION AREA
POWER POLE
DIRT ROAD
DIRT ROAD
2-in. DIAMETER PVC PIPE
16 SPRAY HEADS MOUNTED ON 30-in. PVC RISERS
POWER POLE
BASIN NO. 7
BASIN NO. 8
DIRT WINDROW
FEET
0
50
100
METERS
0
10
20
30
N
POWER POLE

Figure 30. The Negro Bay recharge area.

marls neither lend themselves well to the construction of berms around the ponds nor to stabilized banks as do the soils in Golden Grove. Erosion of the sidewalls contributed to the plugging of the bottom surface of the basins.

Each pond was initially run on a constant-head basis where the ponds were filled to a certain depth and then the flow was throttled down to try to maintain that depth. This was not satisfactory over a long-term basis as the ponds took so little water that the setting had to be too low for effective operation. The average percolation rate based on bottom area was so low that work in the Negro Bay area was suspended and the remaining efforts were applied in the Golden Grove area.

SECTION VII

MONITORING ACTIVITIES DURING THE PROJECT

As part of the project an extensive monitoring program was established to provide data for a "before, during, and after" look at the various parameters that might be affected by the recharge operations. It was desired to carefully monitor surface and groundwater quality and quantity in the study area and, in addition, monitor the operation of the AWWTP.

WATER QUALITY

A water quality laboratory was established within 3 months of project operation on St. Croix. This was first located in the field office, then in laboratory space donated by the Martin Marietta Alumina Company, and finally in February, 1973, in the permanent laboratory which was constructed as part of the AWWTP facility.

The number of parameters analyzed was increased as laboratory facilities improved. Initially a chemist was brought in from the mainland to do the work and to train local people for the work so that he could phase himself out.

In addendum No. 1 of the original project proposal (FWPCA-1970), a list of analyses to be performed during the project was noted and is as follows:

Specific conductivity
Chemical oxygen demand
Biochemical oxygen demand
Total nitrogen
Ammonia nitrogen
Nitrite nitrogen
Nitrate nitrogen
Phosphate
Total organic carbon
Chloride
Coliform

To these tests were added those for alkalinity, calcium, and total hardness plus operational tests for the AWWTP.

All of these analyses were performed on St. Croix with the exception of the total organic carbon and total nitrogen measurements which were performed in the Black, Crow and Eidsness laboratory in Gainesville, Florida.

A survey of the entire study area was made and wells, both public and private, were selected for monitoring purposes. These were located above and below the theorized groundwater flow at the proposed recharge areas. Only active wells were selected for water quality monitoring purposes. These were wells that were being actively pumped, thus assuring a fresh sample of the groundwater for analysis. Additionally sampling points were selected along the course of River Gut where surface water could be sampled. These sampling stations are shown on Figure 16.

To avoid needless duplication of sampling and analysis, the selected wells were divided into two groups, primary and secondary, with the primary wells being considered the most important.

A sampling schedule (see Table 6) was then devised which included all of the sampling stations and all of the analyses scheduled in a systematic fashion that included all of the sampling points in a full analytical time cycle. These time cycles were 4 weeks in length and permitted the chemist time to sample and perform the analyses with a minimum of storage time, and sufficient extra time to maintain the laboratory, prepare reagents, and do the necessary paperwork associated with the laboratory.

In sampling, problems were encountered throughout the project. The greatest was in simply obtaining the samples. Most wells had no provision for sampling taps and these had to be added where permissible so as to sample the water before it was mixed in a storage cistern. Often it was not possible to add these taps, or if they existed, they sometimes were removed at a later time by the owner or alterations were made to the premises which then prevented access to the taps. One has to keep in mind that sampling has continued at some stations for over 4 years.

It was easy to install taps on most of the government-owned wells but these were soon discovered by people who used them during dry periods to either fill up drums of water to take home to fill their cisterns, to provide water to wash cars, or both. This abuse of the government wells often provoked the Public Works Department to remove the sampling taps altogether.

The wells that were drilled adjacent to the Golden Grove recharge area for the purpose of monitoring the changing water levels during recharging were also sampled. Since these had no pumps installed nor easily available power; they were simply dipped, using a project-constructed torpedo sampler. Despite being dipped a few times

TABLE 6. WATER AND WASTEWATER QUALITY MONITORING SCHEDULE

Time		Sampling Program			Analysis of water samples													Analysis of wastewater samples*									
Week No.	Day	Primary water samples (P)	Secondary water samples (S)	Wastewater samples (W)	Chlorides	Specific conductance	Hardness	Calcium	Alkalinity	NO_3-N	NO_2-N	NH_3-N	Total P	COD	BOD	TOC	Coliform	Chlorides	Hardness	Calcium	Alkalinity	NO_3-N	NH_3-N	Total P	COD	BOD	MLSS
1	M			W														W									W
	T			W																						W	W
	W	P		W		P	P	P	P						P		P	W							W	W	W
	T			W	P	P																W	W	W	W	W	W
	F			W														W	W	W	W				W	W	W
2	M	P		W								P						W									W
	T			W																		W		W			W
	W		S	W	S	S												W							W	W	W
	T			W			S	S	S																W	W	W
	F			W														W	W	W	W				W	W	W
3	M			W														W									W
	T	P		W						P												W					W
	W			W									P					W						W	W	W	W
	T			W	P	P																	W		W	W	W
	F			W														W	W	W	W		W		W	W	W
4	M			W														W									W
	T	P		W							P			P		P											W
	W			W														W					W	W	W	W	W
	T			W																					W	W	W
	F			W														W	W	W	W				W	W	W

*Conductivity, free chlorine residual and turbidity levels of the wastewater is continually monitored.

at each sampling, this was obviously an inferior method of sampling and the data obtained from these wells should be viewed with this in mind.

The water quality data for the project are presented in tabular form in the Appendix.

GROUNDWATER QUANTITY AND MOVEMENT

A study of groundwater quantity and movement was made using water level data from wells selected in the study area. These wells were generally inactive nonpumping wells on public and private property. Water level recorders were placed on a series of wells to ascertain what continual variations took place while other wells were simply measured by using a tape measure at regular intervals. Since a free water table does not exist in the study area south of the Centerline Road, these water levels represent the potentiometric surface of the groundwater rather than the actual depth of the aquifer.

Aside from these data, additional information on the potentiometric surface was gathered by installing small diameter, 3/4-in. (1.9 cm) PVC, tube wells in the vicinity of the proposed recharge area. Holes for these wells were dug using a 4-in. (10 cm) soil boring rig with an auger bit. This gas-powered drilling rig was mounted on a trailer which could be moved rapidly from site to site. Although the rig could drill holes quickly in the tight clayey soil, it could not penetrate far below the existing water in the soil as the sides of the holes in the vicinity of the water would collapse as the sectioned auger was being removed to clear the hole. Since all of the holes were drilled during a period of excess groundwater in the area, the resultant tube wells were not deep enough to be usable during the extended period of dry weather that occurred during the last 2.5 years of the project. Additionally the majority of the tube wells downstream of the recharge area were destroyed during the construction of the adult correctional facility. Most of the tube wells upstream of the recharge area were lost in two fires which swept the area and those that survived went down to the blades of a large government-owned cane cutter which made intermittent unpredictable forays into the area to cut forage for the island's cattlemen.

However, the tube wells did furnish useful information in initially calculating the flow pattern of groundwater in the area, which aided in the final placement of the recharge structures. Moreover the actual boring of the holes produced valuable data on the soil horizons in that part of the study area.

The water level data for wells in the study area are presented in graphical form in the Appendix.

RAINFALL DATA

Initially three recording rainfall gages of the weighed bucket type were installed in various parts of the study area to collect rainfall data.

On the aggregate this data collection system was not even a moderate success. The gages suffered from mechanical breakdown, human abuse, and animal interference.

The clock portion of the gages continually broke down. Repairs were difficult to procure on the island and the replacement spring-driven clocks cost close to $100 each. Several replacements were purchased but they soon failed in operation.

Additionally, the rain gages seemed to exude a magnetic pull for human curiosity and at two of the locations the security lock was frequently twisted off the case and the gage thoroughly examined. At the Negro Bay location the gage was located adjacent to a government well and was repeatedly broken into to obtain the bucket, which apparently was used in conjunction with the well to wash cars.

Another problem was animal interference, which at the Bodkin location above Fountain Valley, took the form of the gage being used as a rubbing post by cattle. There was also the general problem of the local tree lizards, Anolis acutus, which would occasionally be found living in the gage. This selection of dwelling place was no doubt accidental on their part and probably the result of falling through the narrow funnel-shaped opening which directs the rain to the weighing bucket. Once trapped inside, the lizard would repeatedly jump on the recording needle, thus distorting the recording. They would eventually die, attracting large numbers of ants who would invade the gage to consume the body.

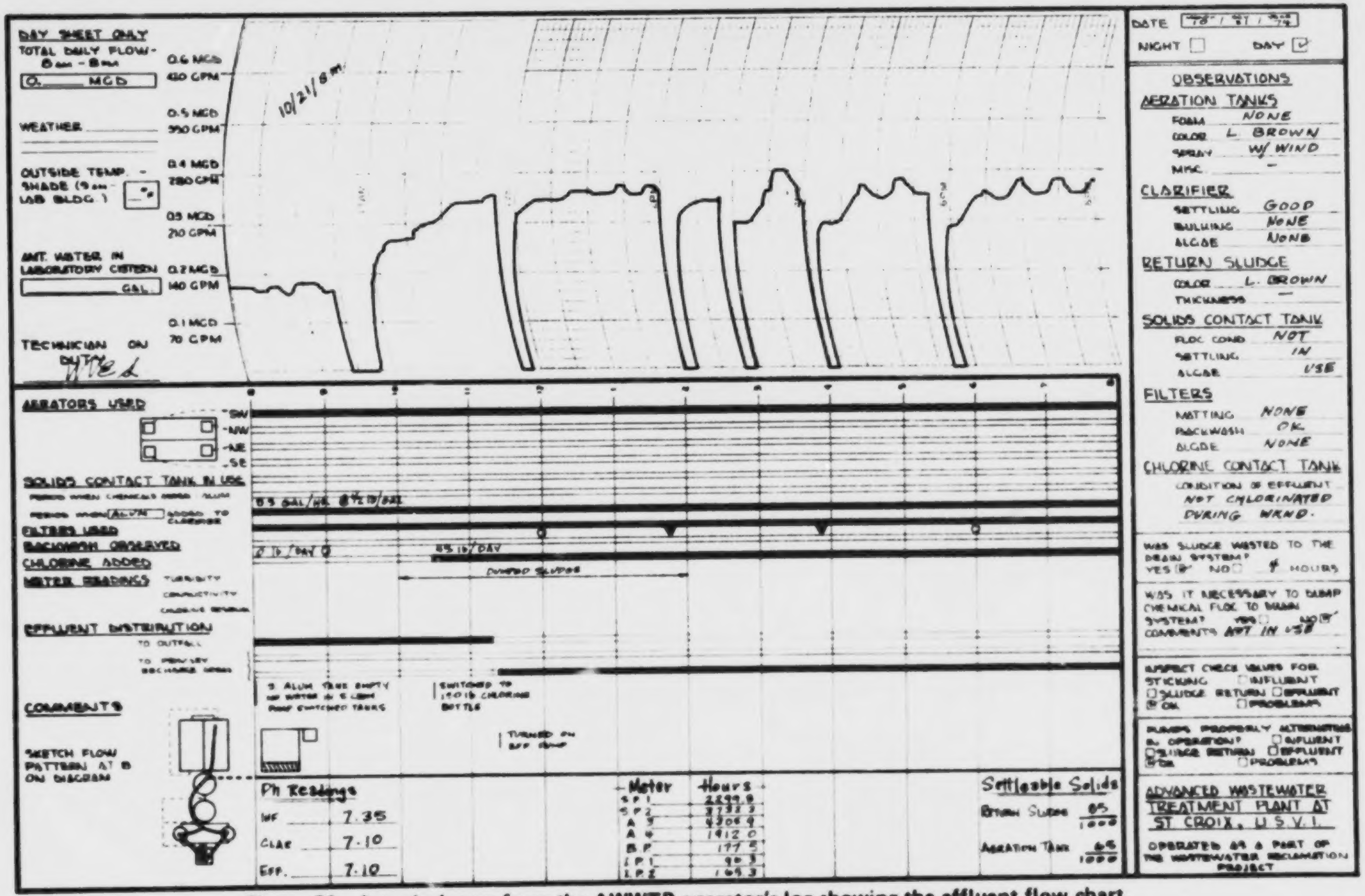
The only gage remaining after the first 3 years was the one installed at the fire station in Grove Place. This gage remained relatively unscathed but has suffered from numerous and continuous clock failures.

Fortunately, the U.S. Department of Agriculture maintains a rain gage at Bethlehem Upper Works, which is on the eastern edge of the study area on a hill just above the Golden Grove recharge area. This gage, which is protected and attended daily, has produced far more reliable information and its data have been used in this report.

ADVANCED WASTEWATER TREATMENT PLANT

The operation of the advanced wastewater treatment plant was monitored as to flow, power consumed, chemicals used, influent and effluent quality, etc. This work was performed by both the plant operators and the project chemist.

The sample log pages displayed in Figures 31 and 32 show how the various plant functions were recorded. These logs required a fair portion of the operator's time to complete every day; but in filling them out and examining the various recorded data that had to be entered into the log, he obtained a better understanding of the plant's operation. The effluent flow chart, Figure 31, was especially helpful in recognizing small problems in operation before they became major disasters. The operating data for the plant have been statistically analyzed and presented in the Appendix of this report.



DATE 10 / 21 / 74
NIGHT ☐ DAY ☑

OBSERVATIONS

AERATION TANKS
FOAM NONE
COLOR L. BROWN
SPRAY W/ WIND
MISC —

CLARIFIER
SETTLING GOOD
BULKING NONE
ALGAE NONE

RETURN SLUDGE
COLOR L. BROWN
THICKNESS —

SOLIDS CONTACT TANK
FLOC COND NOT
SETTLING IN
ALGAE USE

FILTERS
MATTING NONE
BACKWASH OK
ALGAE NONE

CHLORINE CONTACT TANK
CONDITION OF EFFLUENT
NOT CHLORINATED DURING WKND.

WAS SLUDGE WASTED TO THE DRAIN SYSTEM? YES ☑ NO ☐ 4 HOURS

WAS IT NECESSARY TO DUMP CHEMICAL FLOC TO DRAIN SYSTEM? YES ☐ NO ☑
COMMENTS NOT IN USE

INSPECT CHECK VALVES FOR STICKING ☐ INFLUENT ☐ SLUDGE RETURN ☐ EFFLUENT ☑ OK ☐ PROBLEMS

PUMPS PROPERLY ALTERNATING IN OPERATION? ☐ INFLUENT ☐ SLUDGE RETURN ☐ EFFLUENT ☑ OK ☐ PROBLEMS

ADVANCED WASTEWATER TREATMENT PLANT AT ST CROIX, U.S.V.I.

OPERATED AS A PART OF THE WASTEWATER RECLAMATION PROJECT

DAY SHEET ONLY
TOTAL DAILY FLOW - 8am - 8am
0. MGD

WEATHER

OUTSIDE TEMP. - SHADE (9am - LAB BLDG.)

AMT. WATER IN LABORATORY CISTERN GAL.

TECHNICIAN ON DUTY

AERATORS USED
SW
NW
NE
SE

SOLIDS CONTACT TANK IN USE
PERIOD WHEN CHEMICALS ADDED ALUM
PERIOD WHEN ALUM ADDED TO CLARIFIER
0.5 GAL/HR 8½ lb/GAL
FILTERS USED
BACKWASH OBSERVED
CHLORINE ADDED
0 lb/DAY
85 lb/DAY
WATER READINGS TURBIDITY CONDUCTIVITY CHLORINE RESIDUAL
DUMPED SLUDGE
EFFLUENT DISTRIBUTION
TO OUTFALL
TO PROVIDENCE RECHARGE AREA

COMMENTS
3 ALUM TANK EMPTY NO WATER IN 5 LEFT PUMP SWITCHED TANKS
SWITCHED TO 150 lb CHLORINE BOTTLE
TURNED ON EFF PUMP

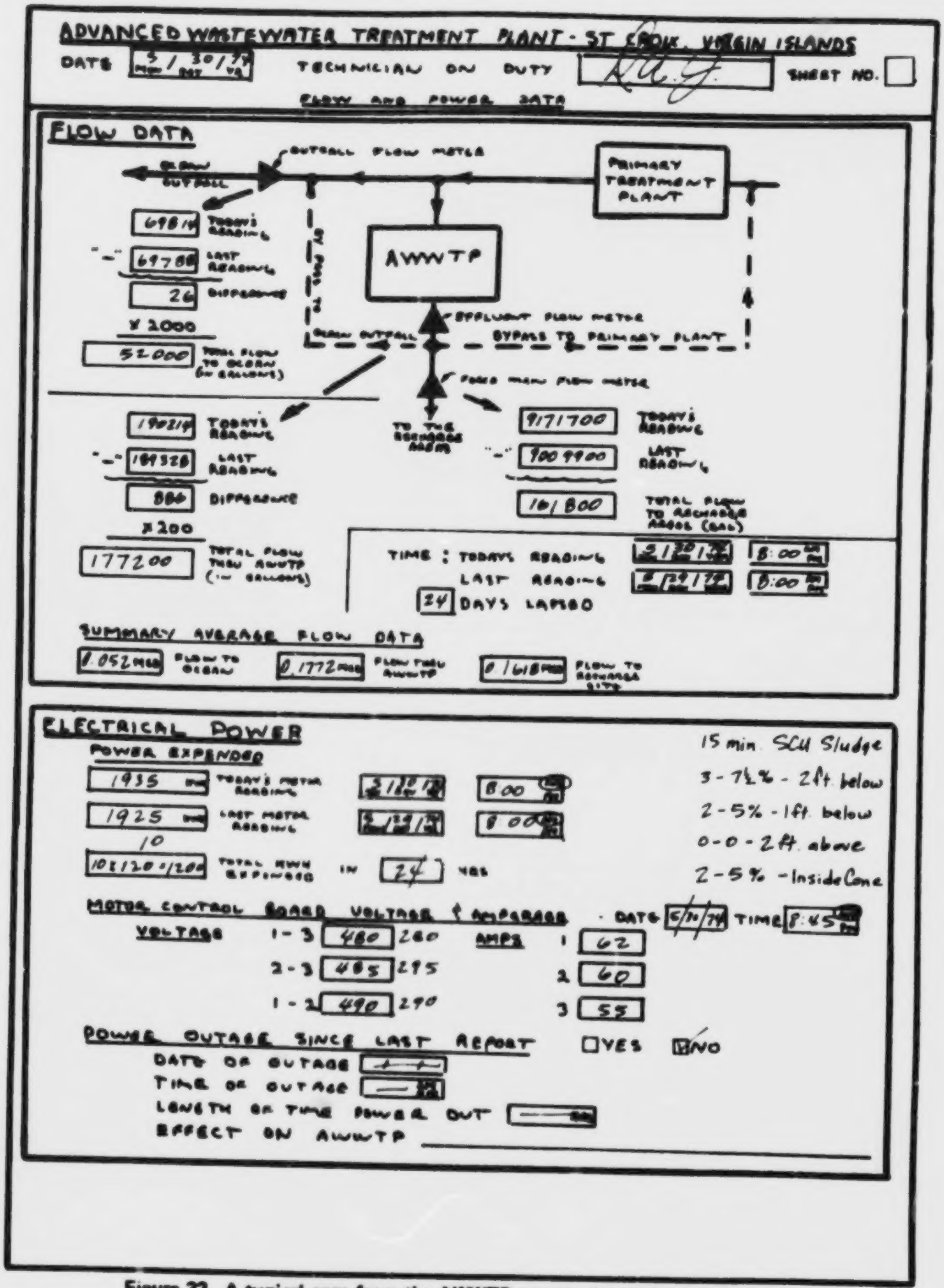
SKETCH FLOW PATTERN AT B ON DIAGRAM

Ph Readings
INF 7.35
CLAR 7.10
EFF. 7.10

Meter	Hours
S P 1	2299.8
S P 2	3733.3
A 3	4306.9
A 4	1912.0
B P	177.5
I P 1	90.3
I P 2	169.3

Settleable Solids
Return Sludge 85/1000
Aeration Tank 65/1000

Figure 31. A typical page from the AWWTP operator's log showing the effluent flow chart.



OUTFALL FLOW METER
OCEAN OUTFALL
PRIMARY TREATMENT PLANT
AWWTP
EFFLUENT FLOW METER
OCEAN OUTFALL
BYPASS TO PRIMARY PLANT
FORCE MAIN FLOW METER
TO THE RECHARGE AREA

ADVANCED WASTEWATER TREATMENT PLANT - ST CROIX, VIRGIN ISLANDS

DATE 5 / 30 / 79 (MON / DAY / YR) TECHNICIAN ON DUTY R.C.J. SHEET NO. ☐

FLOW AND POWER DATA

FLOW DATA

69814 TODAY'S READING
"–" 69788 LAST READING
26 DIFFERENCE
× 2000
52000 TOTAL FLOW TO OCEAN (IN GALLONS)

190214 TODAY'S READING
"–" 189328 LAST READING
886 DIFFERENCE
× 200
177200 TOTAL FLOW THRU AWWTP (IN GALLONS)

9171700 TODAY'S READING
"–" 9009900 LAST READING
161800 TOTAL FLOW TO RECHARGE AREAS (GAL)

TIME : TODAYS READING 5/30/79 8:00 AM
LAST READING 5/29/79 8:00 AM
24 DAYS LAPSED

SUMMARY AVERAGE FLOW DATA

0.052 MGD FLOW TO OCEAN
0.1772 MGD FLOW THRU AWWTP
0.1618 MGD FLOW TO RECHARGE SITE

ELECTRICAL POWER

POWER EXPENDED

1935 KWH TODAY'S METER READING 5/30/79 8:00 AM
1925 KWH LAST METER READING 5/29/79 8:00 AM
10
10 x 120 = 1200 TOTAL KWH EXPENDED IN 24 HRS

15 min. SCU Sludge
3 - 7½% - 2 ft. below
2 - 5% - 1 ft. below
0 - 0 - 2 ft. above
2 - 5% - Inside Cone

MOTOR CONTROL BOARD VOLTAGE & AMPERAGE · DATE 5/30/79 TIME 8:45 AM

VOLTAGE 1 - 3 480 280 AMPS 1 62
2 - 3 485 295 2 60
1 - 2 490 290 3 55

POWER OUTAGE SINCE LAST REPORT ☐ YES ☑ NO
DATE OF OUTAGE –/–/–
TIME OF OUTAGE —
LENGTH OF TIME POWER OUT —
EFFECT ON AWWTP ______

Figure 32. A typical page from the AWWTP operator's log showing flow data and electric power consumed.

SECTION VIII

RESULTS AND DISCUSSION

WATER QUANTITY CHANGES DUE TO RECHARGING

Infiltration and Percolation

A key factor in the economic success of a surface method of artificial recharge is the rate of infiltration. This determines the land area required per unit of recharged water. On the Virgin Islands land is expensive, averaging about $10,000/acre ($4,050/ha).

In comparing the rates of infiltration between the 8 basins as shown on Figure 33, it is apparent that there is a distinct difference between the rates in the 2 basins in Negro Bay and the 6 basins in Golden Grove. The sustained infiltration rate in Negro Bay was less than 5 gpd/sq ft (0.2 cum/day/sq m) while infiltration rates in the Golden Grove basins ranged from 10 to 28 gpd/sq ft (0.4 to 1.1 cu m/day/sq m).

Negro Bay. In the Negro Bay area, which is located on the Kingshill marl, two methods of surface recharge were tried: spray irrigation and spreading basins. Neither method of surface application proved to be sufficiently successful to warrant further investigations.

The spray irrigation was limited in the rate and extent of application by surface runoff on the spray area. The spray area was constructed on a location with a gentle slope of about 0.031. The water was applied at the rate of approximately 2 gpd/sq ft (0.08 cu m/day/sq m) and once the loading reached about 0.4 to 0.6 gal/sq ft, (0.016 to 0.024 cu m/sq m), any additional water would tend to runoff down the slope causing soil erosion. This meant that spraying periods were limited to between 5 and 7 hours in a 24-hour period if erosion was to be controlled. During the intervening drying period, evapotranspiration, through the vegetation and the capillary action of the marl, removed the water in the upper soil horizons. The result was no net gain in water entering the marl formation.

One of the main reasons for this infiltration problem is the structure of the upper soil horizon in the spray area. Covering the

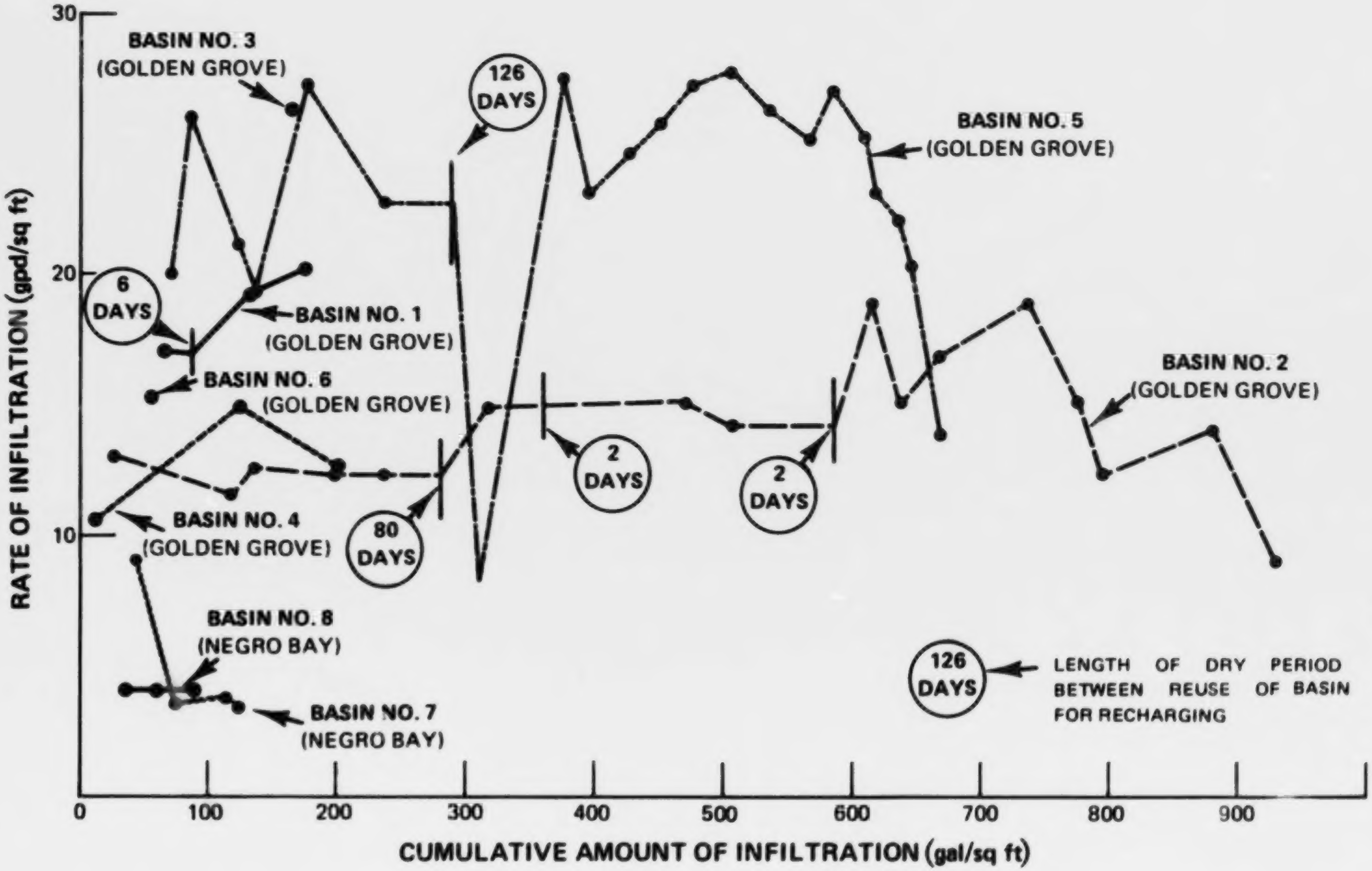


Figure 33. Infiltration rates in the recharge basins.

actual marl formation is a cap of soil approximately 8 in. (20.3 cm) thick. All but 2 to 3 in. (5 to 7.6 cm) of this clayey organic material was removed and windrowed to prepare the area for surface application. It was realized that when wet the clay would swell and tend to be impervious. However, this upper top soil was necessary to serve as a base for growing grasses. The grasses would aid in preventing soil erosion while at the same time they would remove a portion of the nutrients in the applied effluent.

Adjacent to the spray area (see Figure 30) two spreading basins, basins 7 and 8, were each operated for approximately 2 weeks. The resulting sustained rate of infiltration was less than 4 gpd/sq ft (0.16 cu m/day/sq m). This was a better infiltration rate than for the spray irrigation site, but it was not high enough when compared to the rates in Golden Grove to justify continued operation. Additionally, the banks of the marl basins were unstable when wet. The fine material from the banks was eroded to the bottom of the basin, which contributed to the sealing of pore spaces in the exposed marl. Marl, by itself, will support only sparse vegetation to a very limited degree so the use of grass for stabilization was not possible.

In summary the results of the work in Negro Bay showed that artificial recharge by spray irrigation or spreading basins in that area was not justified when compared to the alternative available. This alternative is in Golden Grove where the sustained recharge rates are 4 to 7 times higher and hence the land area required would be proportionally less. Recharge operations in Negro Bay were abandoned in August, 1974, and all subsequent efforts were concentrated on the Golden Grove facility.

Golden Grove. This recharge area, which is located in an alluvial valley, was in operation from February through October, 1974. All the recharging work in this area was accomplished by the use of spreading basins. The resulting rates of infiltration for the various basins are shown in Figure 33. These data show a high sustained rate for infiltration and percolation for all of the basins with the minimum rate being in the order of 11 gpd/sq ft (0.45 cu m/day/sq m). The best infiltration rate was encountered in operating basin 5 which had a maximum sustained rate of infiltration in the range of 25 gpd/sq ft (1.0 cu m/day/sq m).

The rate of infiltration is a function of both the soil structure on, and immediately below, the bottom of the basins and the inherent ability of the underlying formation to conduct the percolating water away from the vicinity. If the underlying formation will not remove the introduced water at the same rate that it is being applied, then ponding will occur.

In order to test the long-term ability of the underlying formation to handle recharging, basin 2 was operated continuously for 60 days. A sustained decline in infiltration rate was not apparent until the final 10 percent of the run. By that time a cumulative loading of about 660 gal/sq ft (26.9 cu m/sq m) had been applied to the basin for a total flow of about 6.6 mil gal (24,981 cu m).

Basin 5 was also operated for an extended period of time to test its capabilities. After a dry cycle of 126 days the basin was operated at a high rate of loading for 18 days. During this time the rate of infiltration averaged about 22 gpd/sq ft (0.9 cu m/day/sq m) compared with 11 gpd/sq ft (0.45 cu m/day/sq m) for basin 2 discussed in the preceding paragraph. The total loading for the run was about 400 gal/sq ft (16.32 cu m/sq m). The infiltration rate dropped off drastically during the final portion of the run and there were indications of ponding at that time. These were manifested by some dampness at the bottom of the adjacent structure, basin 6.

The decrease in infiltration rates which occurred in both basins 2 and 5 could be caused by clogging of the soil in the basin due to deposition of suspended solids and/or biological growth; or, to the mounding of the water table to the point where it reached the bottom of the basin. Based on observations, examination of water level information, and comparison of infiltration rate data, it is believed that clogging of the soil was involved in both cases but that the mounding water level under the basins also played a part. This is especially true in the case of basin 5 during its final extended run.

The clogging condition of the soil due to deposition of organic suspended solids and biological activity is readily reversed by a period of drying so that stable aerobic conditions are restored to the upper soil horizons. This permits aerobic metabolic activity to occur in that area.

The low turbidity and organic content of the wastewater effluent used in this recharging reduced considerably the potential suspended solids involved in mechanical entrapment, while also reducing the food available for microbial growth. In order to continue the long periods of inundation which are vital to the economics of the recharge operations, it is important to continue the operation of the AWWTP so that the present low levels of turbidity and organic content are maintained, or reduced.

The short span of recharge operations in 1974 did not permit sufficient data to be collected to determine the most efficient time period to use for either the inundation of the ponds (wet days) or the intervening drying period (dry days). It will probably take several years of operation and careful monitoring to correctly arrive at the answer. It is likely that there will be different values for each pond due to the difference in underlying strata.

For the present, however, operations should be carried out on the basis of 10 wet days, followed by 5 dry days. This will give a complete cycle of 15 days for which an average value for the entire cycle of 8 gpd/sq ft (0.33 cu m/day/sq m) can be used for loading purposes. When operations are renewed then these figures can be updated as experience dictates.

Groundwater Movement in the Golden Grove Area

St. Croix's physiography in general and stratigraphy in particular create some problems for the groundwater hydrologist. The island's groundwater situation is studied most easily on a broad plane where generalizations can be made on well yields, aquifer flows, and transmissibility. The USGS has done this in useful reports such as those recently published by Jordan (1973) and Robison (1972). These reports combined collected data to present an overall view of the groundwater potential on the island.

As the area of study in St. Croix is reduced to a single drainage basin, or portion thereof, the difficulties involved in accurate analysis can increase drastically. This project has intensively studied the portion of River Gut where it passes through Golden Grove. The area of interest is the alluvium in the valley into which the artificially recharged water is introduced. Information about the alluvium has been gained mainly by soil borings, well construction, pumping tests, water level monitoring, chemical analysis of water samples, and field observations.

The results of all of these investigations have shown that this area is one of extreme complexity when studied as a separate small system. The alluvium is of recent geologic origin and its placement has been a result of years of deposition of material weathered from the basin's surrounding hills. This was deposited by both normal stream sediment transport and by occasional turbulent flooding conditions. The result has been a formation of an alluvial material which is generally heterogeneous and anisotropic in character. It is estimated that field permeability (K_f) values for the alluvium range from 0.01 to 10,000 gpd/sq ft (0.0004 to 410 cu m/day/sq ft) and vary in both horizontal and vertical planes. While all of the material will conduct water to some extent, the main aquifers composed predominately of sand and gravel conduct the major portion of the flow. Based on borings, well construction samples, and observations, these aquifers are neither consistent in thickness, material content, nor horizontal extent. Their thickness ranges from 0.5 to 15 ft (0.15 to 4.57 m) but generally in the order of 1 to 2 ft (0.3 to 0.6 m) thick.

Pumping Test Analysis. Pumping tests were performed on selected wells in the area. However, analyzing the data to provide valid, meaningful results as to permeability (K), transmissibility (T), and the coefficient of storage (S), for each well is not possible to any reasonable degree of accuracy.

The reason for this is that many of the assumptions on which the accepted theories and calculations for these parameters are based are not valid in the situation at hand. Of the 7 assumptions listed by Kruseman and DeRidder (1970, p. 111) which are basic to any conventional analysis, 3 of them cannot be fulfilled. These are:

> The aquifer has an apparently infinite areal extent.
>
> The aquifer is homogeneous, isotropic, and of uniform thickness over the area influenced by the pumping test.
>
> Prior to pumping, the piezometric surface and/or phreatic surface are (nearly) horizontal over the area influenced by the pumping test.

In the first assumption, the aquifers in Golden Grove have a very real boundary situation where the horizontal extent of the aquifer varies from only 200 to 1,200 ft (60 to 365 m).

In the second assumption the aquifer is not homogeneous, isotropic, or uniform in thickness.

As for the final assumption, the potentiometric surface slopes steeply at the rate of 50 to 70 ft/mile (10 to 13 m/km) within the alluvium.

Aquifers in the Recharge Area. There are a number of aquifers in the alluvium, some of which are shown in Figures 18 and 20. They are not necessarily connected horizontally, and isolated sand and gravel lenses are not uncommon. Precise knowledge of the strata can only come from additional deep borings; the more borings the better will be the knowledge of the area. However based on borings and well logs available, information on recharge rates and water levels, observations in the field, and engineering judgment; certain tentative conclusions can be made as to the nature of the water-bearing strata in the vicinity of the recharge area. These conclusions are discussed in the following paragraphs.

There are one and possibly two main aquifers that transmit the major portion of the groundwater in the upper aquifers through the recharge area. The theorized location of these aquifers is shown on Figure 34. The field permeability (K_f) value in the most porous section of the main aquifer is in the range of 3,000 to 7,000 gpd/sq ft (122 to

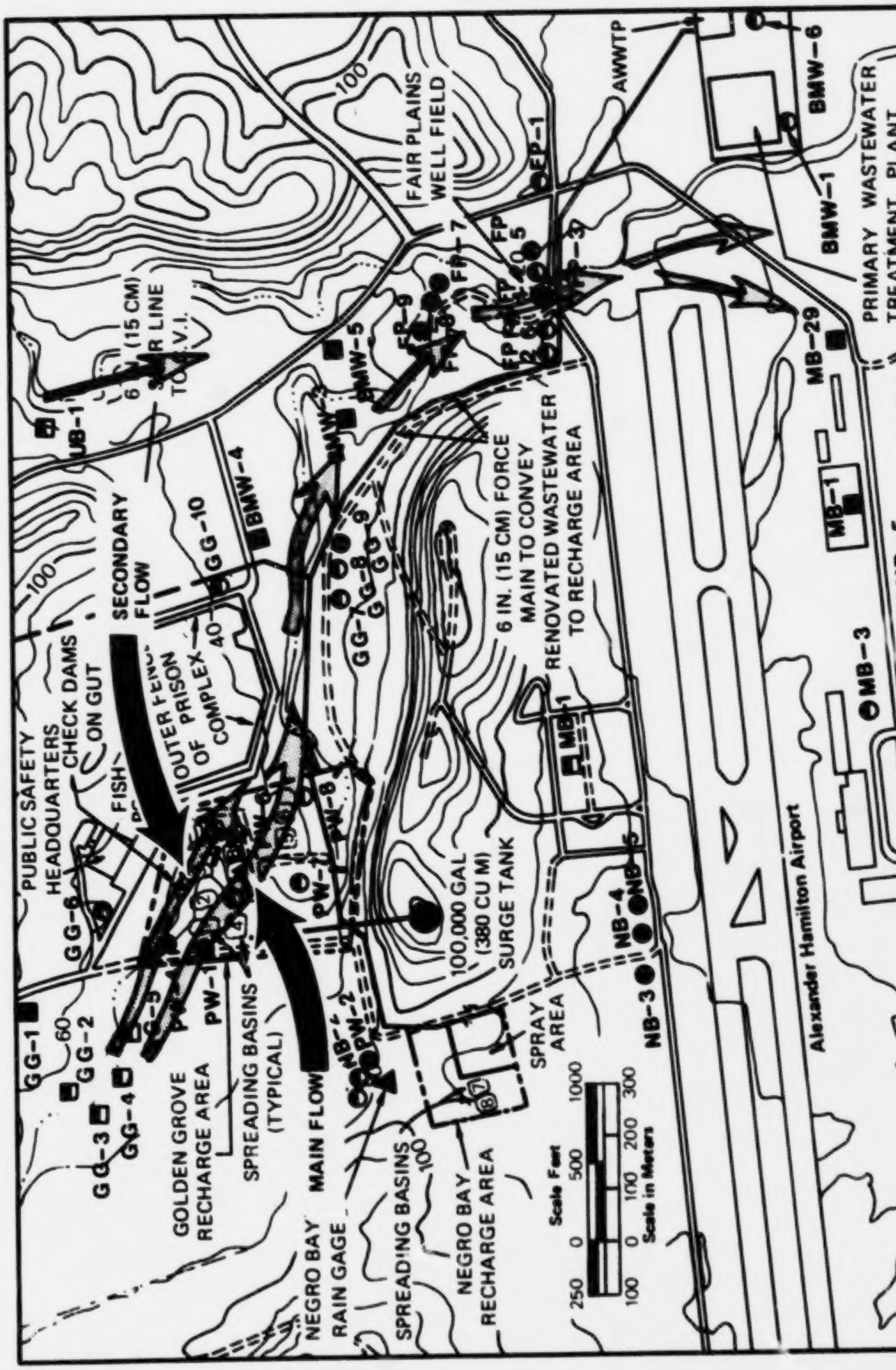

GG-1
GG-2
GG-3
GG-4
GG-5
GG-6
GG-7
GG-8
GG-9
GG-10
60
100
40
PUBLIC SAFETY HEADQUARTERS
CHECK DAMS ON GUT
FISH
OUTER FENCE OF PRISON COMPLEX
SECONDARY FLOW
MAIN FLOW
GOLDEN GROVE RECHARGE AREA
SPREADING BASINS (TYPICAL)
PW-1
PW-2
PW-8
NB-2
NB-3
NB-4
NB-5
NEGRO BAY RAIN GAGE
SPREADING BASINS
NEGRO BAY RECHARGE AREA
SPRAY AREA
100,000 GAL (380 CU M) SURGE TANK
6 IN. (15 CM) FORCE MAIN TO CONVEY RENOVATED WASTEWATER TO RECHARGE AREA
6 IN. (15 CM) SEWER LINE TO V.I.
UB-1
BMW-4
BMW-5
BMW-1
BMW-6
FAIR PLAINS WELL FIELD
FP-1
FP-3
FP-5
FP-7
FP-9
AWWTP
MB-1
MB-3
MB-5
MB-29
PRIMARY WASTEWATER TREATMENT PLANT
Alexander Hamilton Airport
Scale Feet
250 0 500 1000
Scale in Meters
100 0 100 200 300

Figure 34. Hypothesized flow of groundwater in the upper aquifer in Golden Grove.

285 cu m/day/sq m). This was determined by approximating the system during recharging as a constant head parameter. The resulting K_f value checks with the range of K values for aquifers with sands and gravels given by Todd (1959, p. 53) and Davis and DeWiest (1966, p. 164). The average temperature of groundwater on St. Croix is about 27° C which decreases viscosity and increases the K by approximately 33 percent (Todd, 1959, p. 51).

It is believed that a portion of the main aquifer was partially exposed during the excavation of the new stream channel recently constructed just south of the adult correctional facility. Based on the recharge operations, it is estimated that the major aquifer below the basins has a main transmitting area of approximately 600 sq ft (55 sq m). This aquifer traces the course of an old streambed across the area.

Basins 1, 4, 5, and 6 are located wholly, or in part, over the probable location of the main channel. Basin 2 is interconnected to it by a thinner sand lens. The nature of the interconnection of basin 3 is not clearly understood due to its limited period of recharging. None of the project wells are located within the main channel in Golden Grove since its presence was not suspected until after the wells were constructed. Wells PW-7 and PW-8 are apparently isolated from the main aquifer while wells PW-5 and PW-6 are connected to it via sand lenses. Wells PW-1 and PW-4 are located on either side of the main aquifer but are probably connected to it by a thin transverse aquifer which continues north underneath the stream.

Water Level Response to Recharging. An examination of the water levels in the various wells in the area compared with the rainfall and periods of artificial recharge reveals many points of interest.

In Figure 35, the general water levels during 1973 dropped due to the lack of sufficient natural recharge from rainfall. Both wells GG-3 and GG-5 are upstream of the recharge area. GG-3 was selected as the control well since activity in the recharge area did not appear to affect it. After recharging began in 1974, GG-5 was almost immediately affected, as can be seen in Figure 35. The flattening of the slope of this well beginning in March was due to the hindrance of the normal flow in the upper aquifers due to the recharge water added to the same aquifer.

Figure 36 compares the immediate boundary wells on the approaches to the recharge area with a well, PW-8, within the area. GG-13 is 1,500 ft (425 m) north of the area. A-18 is 3,700 ft (1,130 m) northwest of the recharge area at the upper end of the aquifer which flows under the basins. GG-3 is in the same general aquifer system as A-18 and 1,300 ft (400 m) upstream of the basins. The lack of activity in these boundary wells indicates that outside influences such as rainfall are not

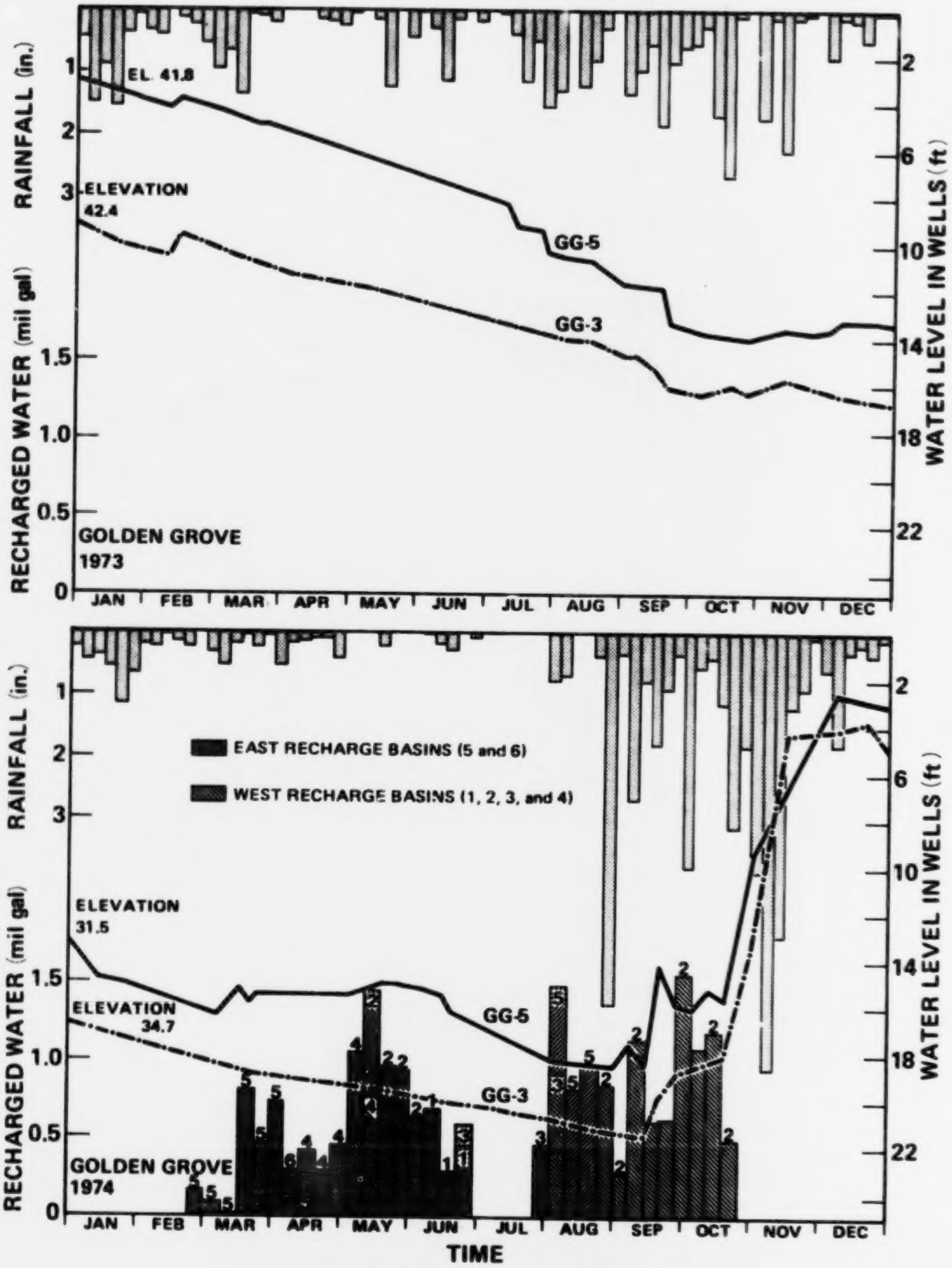


Figure 35. Comparison of wells GG-3 and GG-5, 1973–1974.

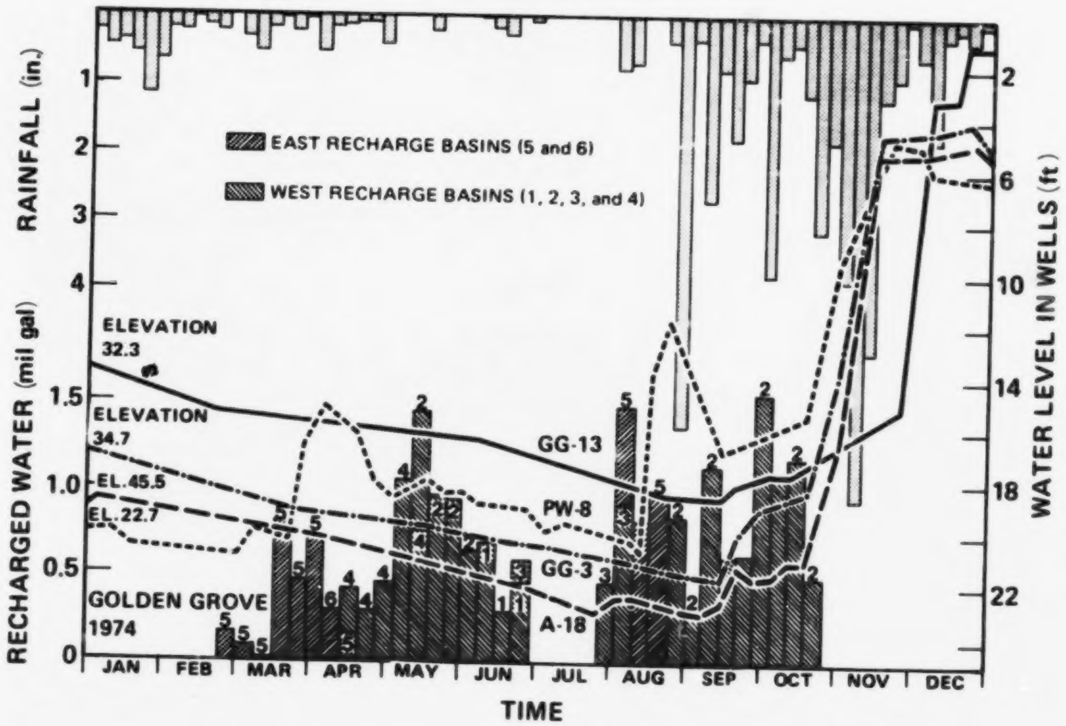


Figure 36. Comparison of wells A-18, GG-3, GG-13, and PW-8, 1974.

disturbing the groundwater system. Hence the reaction of PW-8 is, in fact, caused by the artificial recharge operations taking place within the localized area of Golden Grove.

Figure 37 is significant in two ways. First it shows the extent of water level alterations caused by recharging, as measured in wells in the vicinity of the basins during 1974. Well PW-6 is plotted along with control well GG-3. During 1975, when no recharging took place, the rainfall during the first 7 months was very similiar to that of the previous year. Again PW-6 and GG-3 are plotted and it should be noted that they move almost in unison. The inference is that this is the pattern that the water levels would have taken during 1974, had artificial recharge not taken place.

The second manner in which Figure 37 is significant is in the response that PW-6 exhibits when recharging is switched from the eastern to the western basins during the first week in April, 1974. Whereas PW-6 responded almost immediately to recharge in the eastern basins, there was a delay of approximately 15 days before it responded to the operation of basin 4. This delay is attributed to the initial slaking of the soil and filling of the pore space combined with the hydraulic travel time from the basin to the monitor well. This response pattern is repeated in the latter part of August with a similiar switch from an eastern to western basin.

The response of PW-8 to recharging (see Figure 38) is indicative of a well which is located within a sand lens that is not interconnected to the aquifer carrying the major portion of flow from the basins. The lens is, however, adjacent to the eastern basins.

The response of PW-6 to recharging appears to demonstrate that it is in a sandy lens which is interconnected to the lower part of the main aquifer area. The interconnection is hydraulic and does not consist of water flowing rapidly through the lens.

PW-7 is isolated from the basins and main aquifer area. Its water level variations are damped out considerably and they depend on seepage through a less porous soil.

Recharged water entering the upper aquifer system from the basins moves laterally through the aquifers in a general east-southeasterly direction. As the water moves along the aquifer it satisfies the storage demand of any of the unsaturated soil in the vicinity. The main lateral velocity is believed to be in the range of 15 to 25 ft/day (4.6 to 7.6 m/day) in the vicinity of the recharge area while under the direct influence of basin loading. When the groundwater mounding under the basin subsides, and/or if the aquifer dimensions increase substantially, the velocity decreases considerably.

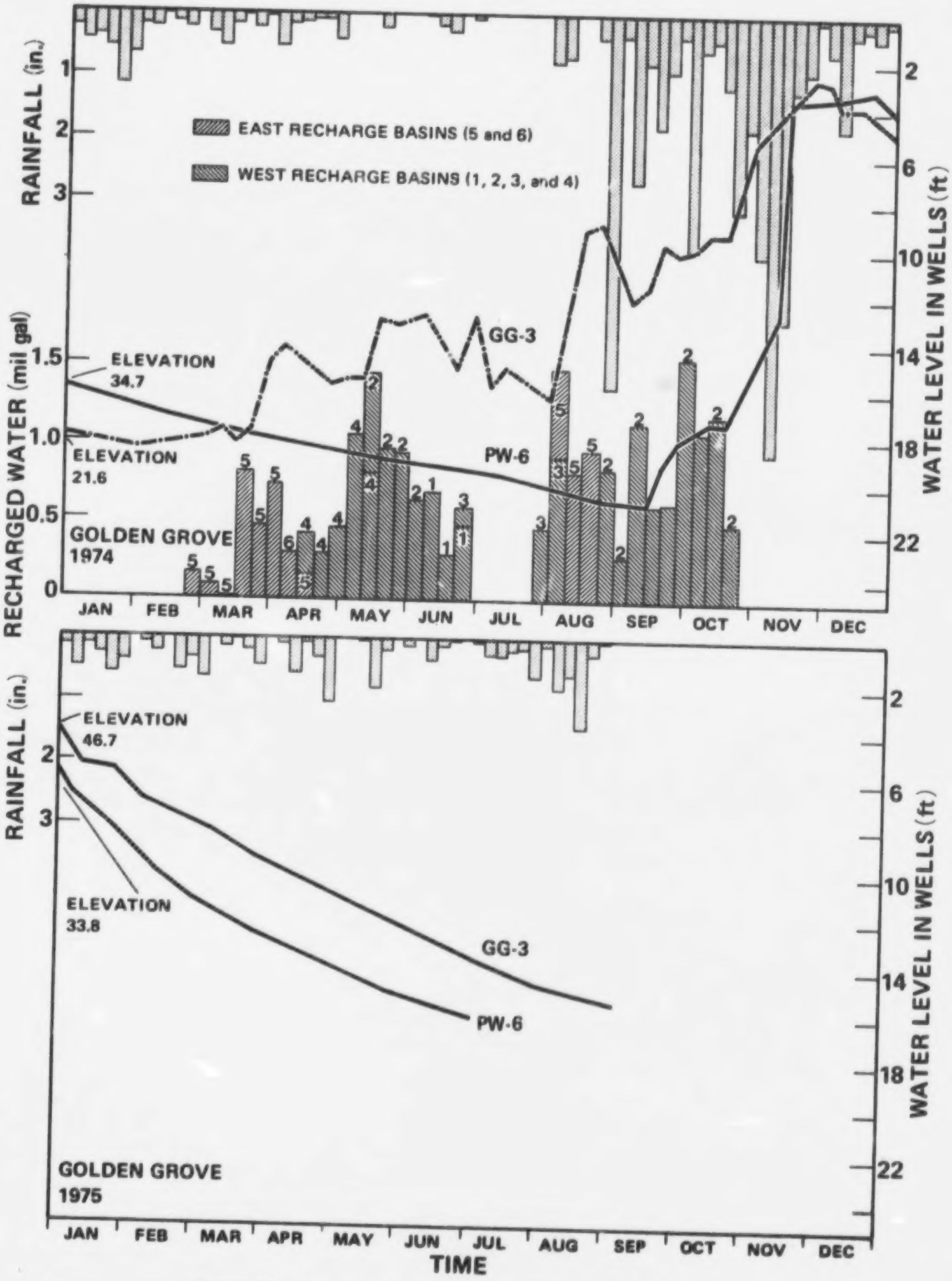


Figure 37. Comparison of wells GG-3 and PW-6, 1974-1975.

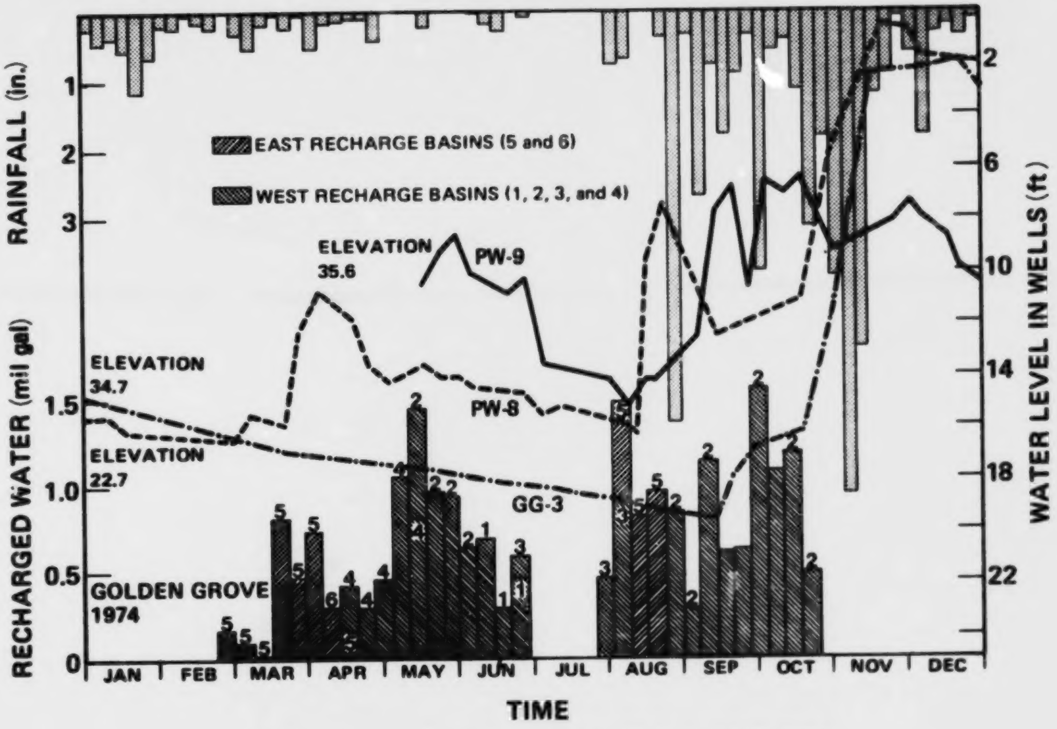


Figure 38. Comparison of wells GG-3, PW-8, and PW-9, 1974.

A generalized view of the changing potentiometric surface in the Golden Grove area during the entire period of the project can be seen in Figures 39 and 40.

Groundwater Augmentation by Artificial Recharge

By comparing two identical sections of the groundwater system, one without and the other with artificial recharging, an approximate idea of the net effect of recharging can be ascertained. Only the immediate area containing, and adjacent to, the spreading basins is considered in this analysis. Once the artificially recharged water has entered the groundwater aquifers and starts its horizontal flow, it is considered as normal groundwater, subject to the same losses that existed without the project.

Figure 41 shows two typical vertical sections of the Golden Grove valley. Each section has the important water inputs and outputs, one section with and the other without a recharge operation taking place. By comparison, the major changes will be in the addition of recharge water and the subsequent increase in flow in the aquifer. Increased consumptive losses will be the added evaporation from the shallow water-filled basin. It can also be expected that evapotranspiration will be increased to some degree in the immediate area due to the additional water available for this either in the aquifer or in the percolating water forming the mound underneath the basin. Percolation between aquifers is believed to be minimal, based upon drilling observations, but might increase with the increased hydraulic head available beneath the inundated basins. However, since extraction of groundwater will take place from all the aquifers in the alluvium, the transfer of water between them will not change the ultimate amount of product.

Thus the major new loss to the recharged system is in the added evapotranspiration due to the available moisture in the pond and soil. Meyer (1952) reported that the average annual evaporation from an open pan in the Anna's Hope area, in central St. Croix, over a 10-year period was 70.2 in./yr (177.8 mm/yr), which averages about 0.19 in./day (4.87 mm/day). This is probably high for the basins due to the rapid turnover of water and consequently its lower temperature. This also neglects the evapotranspiration that no longer occurs from the soil covered by the water in the basin.

Increased evapotranspiration for the sections shown in Figure 41 may be approximated by the difference between Bowden's (1968) highest and lowest monthly evapotranspiration estimates for the Kingshill area adjacent to Golden Grove, which come to 0.12 in./day (3 mm/day). This represents the possible rise in evapotranspiration due to the increased availability of water in the area which, according to Meyer, is a prime factor to be considered.

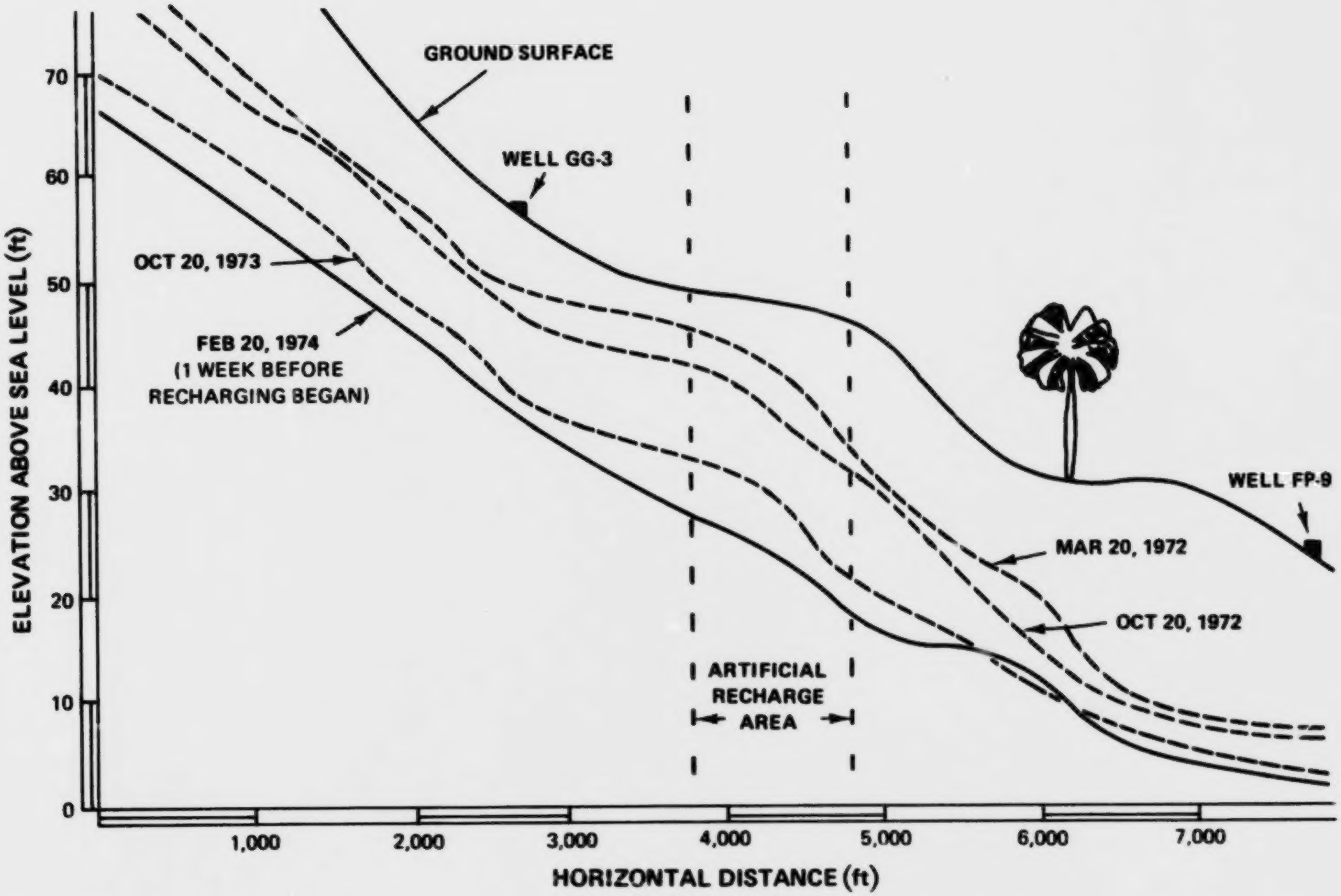


Figure 39. Potentiometric groundwater levels in Estate Golden Grove, 1972-1974.

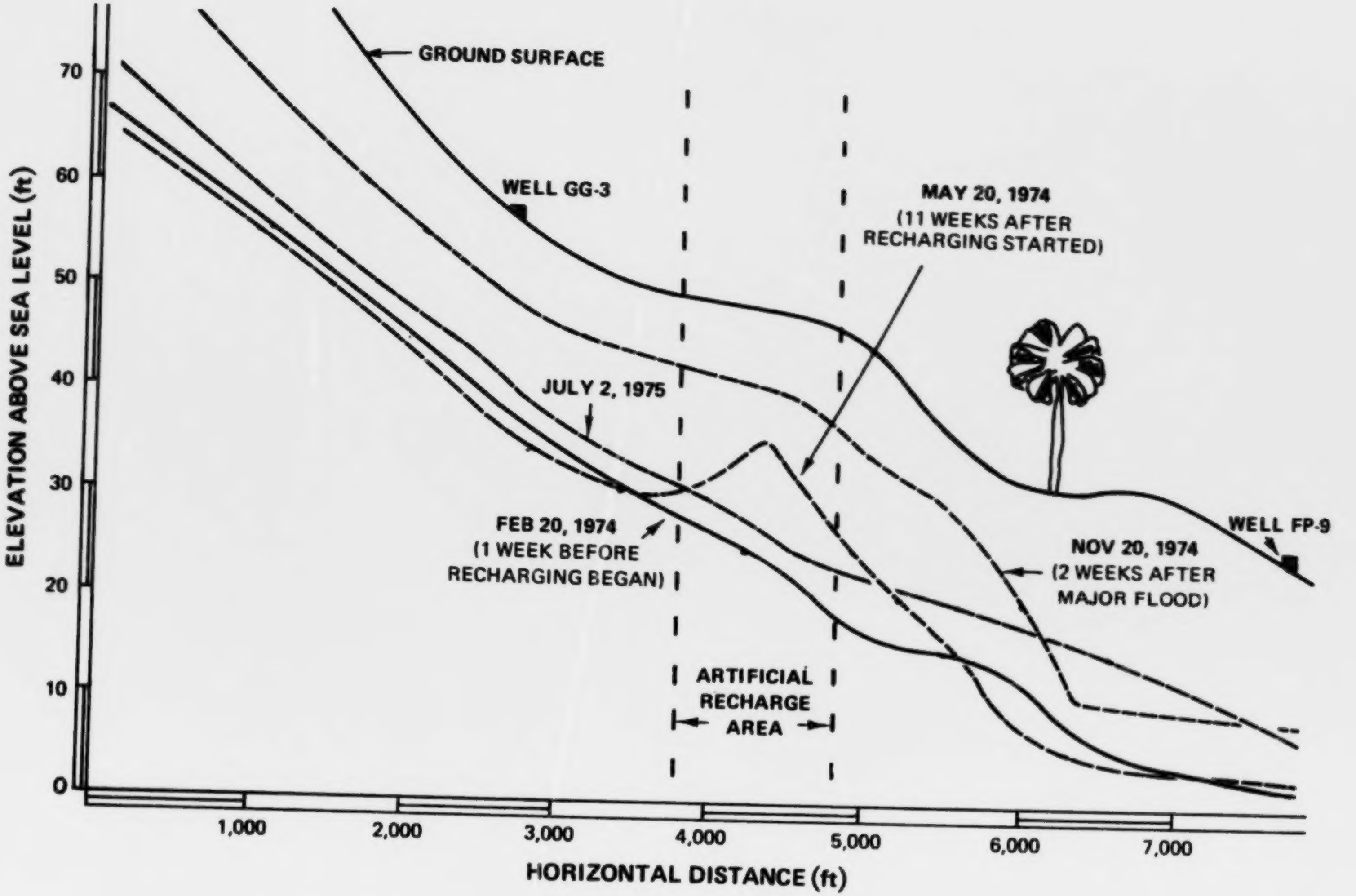


Figure 40. Potentiometric groundwater levels in Estate Golden Grove, 1974-1975.

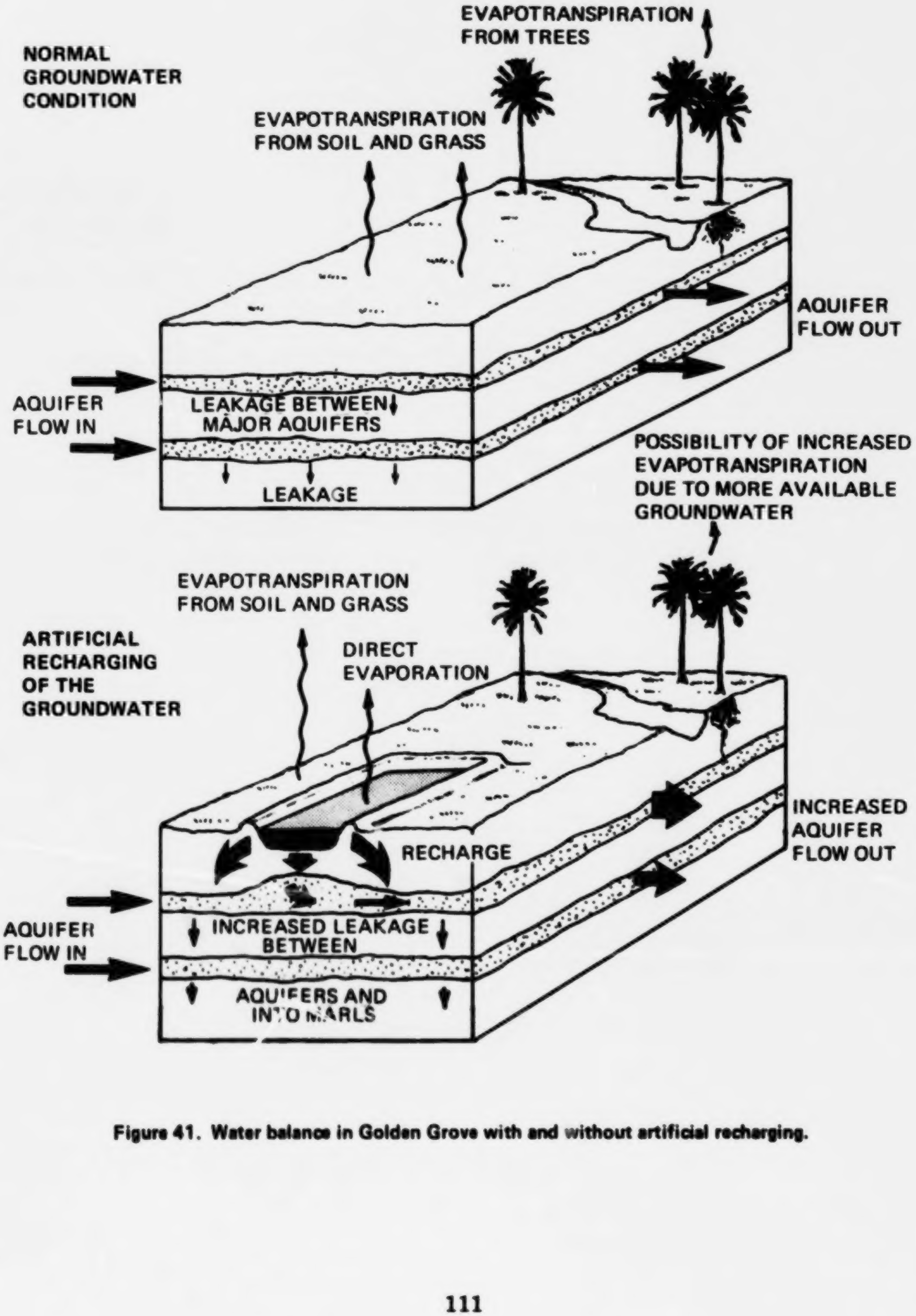

NORMAL GROUNDWATER CONDITION
EVAPOTRANSPIRATION FROM TREES
EVAPOTRANSPIRATION FROM SOIL AND GRASS
AQUIFER FLOW OUT
AQUIFER FLOW IN
LEAKAGE BETWEEN MAJOR AQUIFERS
LEAKAGE
POSSIBILITY OF INCREASED EVAPOTRANSPIRATION DUE TO MORE AVAILABLE GROUNDWATER
EVAPOTRANSPIRATION FROM SOIL AND GRASS
ARTIFICIAL RECHARGING OF THE GROUNDWATER
DIRECT EVAPORATION
RECHARGE
INCREASED AQUIFER FLOW OUT
AQUIFER FLOW IN
INCREASED LEAKAGE BETWEEN
AQUIFERS AND INTO MARLS

Figure 41. Water balance in Golden Grove with and without artificial recharging.

For the largest basin, basin 4, this means a possible total added evapotranspiration loss of about 1,500 gpd (5.5 cu m/day) which may be compared to the average daily infiltration for this basin of approximately 125,000 gpd (473 cu m/day). This represents a loss of about 1.2 percent of the influent to the basin after initial slaking of the soil has taken place at the beginning of every inundation. Other losses do occur, but these are common to both naturally and artificially recharged water in the aquifers. Probably the largest loss of this sort in Golden Grove is that due to the evapotranspiration involved with the large deep-rooted trees adjacent to River Gut. These trees are protected by Virgin Islands law; and although they supply shade, a windbreak, and soil stabilization along the stream bank, they do extract an undetermined quantity of water from the soil.

Attempts of quantifying the amount has not been overly successful. One recent researcher, Rex Meyer (1952, pp. 23-26), discussed transpiration of length in a Department of the Interior report and finally commented that "the difference in plant species and climatic conditions on the island of St. Croix makes it impracticable to apply transpiration ratios determined elsewhere on similiar plants to the vegetation on the island." He concluded his section on transpiration by saying that "it is not possible with the available data to make a reliable estimate of transpiration in any part of St. Croix." This investigation could not improve on this statement but strongly recommends that local research efforts be made in this direction in the future. It is possible that increased soil moisture caused by recharging would increase consumptive use by these trees.

Groundwater extraction efficiency will play a large part in the ultimate economies of the water reuse system. Fortunately the groundwater geology of Golden Grove as portrayed in Figure 18 keeps the groundwater flow within defined bounds where it is relatively easy to tap and withdraw with a minimum of loss. However, the aquifer is thin and in some areas in Golden Grove it is limited in its transmissibility. The entrance losses from these thin alluvial aquifers into the well casing generally would limit the extraction by individual well to about 20 to 30 gpm (1.3 to 1.9 l/sec).

Based on operating results and engineering judgment, the best mode of operation of the recharge facility in the future is to plan to extract 85 percent of the recharged water in the immediate area of the spreading basins. The remainder should be permitted to flow down the aquifer to be used to protect the Fair Plains well field from further saline degradation. The pumping at the Fair Plains well field can then be adjusted to a rate that will efficiently remove the groundwater without permitting a decrease in overall water quality in the area.

WATER QUALITY CHANGES DUE TO RECHARGING

Negro Bay

The operations in Negro Bay did not affect the underlying groundwater to any detectable degree. The two reasons for this are first, little, if any, recharged water reached the marl-limestone interface that was located 15 ft (4.6 m) below the area. This was due to the low rate of infiltration and percolation combined with the high rate of evapotranspiration. Second, even if water did arrive at this interface, it would need to penetrate approximately 60 ft (18 m) of horizontally layered limestone which is above a confined aquifer.

The early termination of operations in Negro Bay combined with the physical difficulties mentioned above essentially preclude the possibility that recharged water reached the aquifer.

Golden Grove

The water artificially recharged into the Golden Grove area had only a minor effect on the groundwater quality in that basin. In order for the monitoring to be valid, only continuously pumped wells were considered in the final evaluation of the project's effects.

Monitor Wells. Due to their location the key wells considered for monitoring the recharge operations were GG-8 and FP-8, downstream of the recharge area, plus PW-1 and PW-4 immediately upstream of the basins. The changing chloride content of these wells was judged to be significant as chloride in groundwater is essentially a refractory substance. As such it is not likely to undergo changes due to biological or physiochemical effects such as phosphates, nitrates, ammonia, and degradable organics can, which is why chlorides are often used as a tracer.

A change of chloride content is possible in the wells if water with a different chloride concentration joins or replaces the existing water source. This would be the case in the pumping wells being monitored when the artificially recharged water, with a different chloride content, moves through the aquifer and encounters them. A graph of the chloride content for these wells and the recharged water is shown in Figure 42.

Well A-16. Figure 42 compares the chloride levels with the rainfall and the quantities of recharged water used during 1974. Well A-16 is a control well and is located above the recharge area at the head of the alluvial valley at Adventure. The location of this well is such that it cannot be affected by the recharging. The changes in chloride content shown for A-16 are those normally experienced by wells in the area.

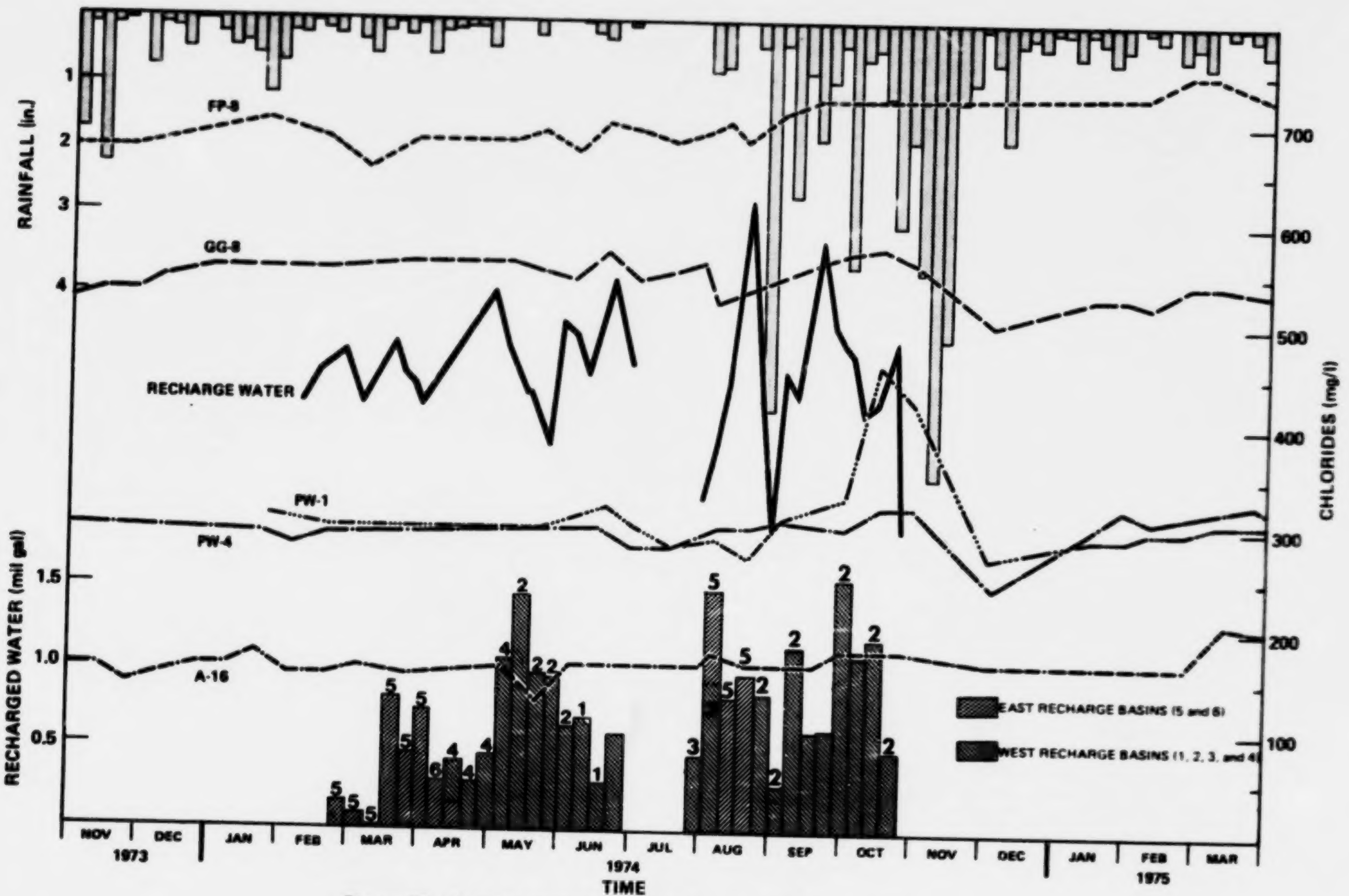


Figure 42. Chloride content of monitor wells in the study area.

Well PW-1. Well PW-1 is located about 200 ft (61 m) upstream of the edge of basin 1. By examination of Figure 42 it is apparent that the recharging affected the chloride content in both June, to a slight degree, and again in September and October. Both of these times were periods when either basins 1 or 2 were in operation. We can expect that the rapid increase during September and October could have been higher had the water added to the aquifer by heavy rainfall in August not occurred. An apparent rise in nitrates from 5.4 mg/l to 6.7 mg/l also occurred at this time but it cannot be substantiated as there is insufficient background data on this well. A pump was not installed on PW-1 until January, 1974, so the data available are limited.

Well PW-4. Well PW-4 also showed some indications of a chloride rise but it was minor. Although this well is only 300 ft (91 m) from basin 1, it is believed that the intervening aquifer structure is connected only in an indirect manner. The water from this well was reduced in chloride concentration during November due to the heavy rains and flooding which naturally recharged the soil over the entire area.

Well GG-8. Well GG-8 is located about 1,500 ft (460 m) downstream of basin 6. The water from this well generally has a chloride content higher than the artificially recharged water. However, this well, like many others on St. Croix, derives its water from more then one aquifer. The method of well drilling on the island is such that it is not possible to separately test the aquifers encountered for water quality. However from field observations and tests made while drilling, indications are that the water in the different aquifers is often of sharply varying chemical character. Thus changes in chemical characteristics in a well water are often caused simply by a variation in the contribution to a well that each aquifer makes. Indications are that the recharge water is probably increasing the chloride content in an aquifer which normally acts as a source of dilution water for well GG-8. The reaction to the early recharging operations is delayed in time due to the rate of flow of the recharged water from the basins to the well itself. The effect of the later periods of recharge are obscured by the heavy rains that occurred in the fall. This well water has had a trend toward increasing chloride content since sampling began in 1971. The mean chloride values for 1971, 1972, and 1973 are 426, 453, and 507 mg/l, respectively. The variation in the other parameters for water from that well fell within a standard deviation of past performance and cannot be considered significant.

Well FP-8. Well FP-8 is located approximately 3,300 ft (1,000 m) downstream of basin 6 when measured along the assumed course of the main aquifer. It is likely that FP-8 receives water from both the River Gut and the Bethlehem Gut drainage basins. FP-8 is probably well 45a referred to by Cederstrom (1950, p. 68). This well was drilled to a depth of 225 ft (68.6 m) through the alluvium and marl and 17 ft (5.2 m) into the Jealousy formation.

Cederstrom reports (1950, p. 84) that the chloride content in 1940 was 510 mg/l. In 1971, 1972, and 1973 the mean chloride content was 640, 649, and 670 mg/l, respectively.

Inspection of Figure 42 shows some indication of increasing chlorides in FP-8 during the latter part of 1974. Although it could be due to the recharged water it cannot, with certainty, be said that this is the cause for the increased chloride content. The water in the Fair Plains well field has been undergoing a general increase in chlorides over the past few years. During 1974, 3 out of the 9 wells in Fair Plains were abandoned due to excess TDS. The water in the adjacent well, FP-7, showed a continuous increase in chlorides from 1973 up to September, 1974. This may have had an influence on FP-8.

The other chemical and biological parameters monitored in the water from the wells did not show significant changes during this period. Had the recharging operations continued longer and/or the floods not occurred, then it is possible that additional changes in the groundwater might have occurred.

With many of the parameters measured it is likely that the concentration of the substance in question underwent changes during the recharging operations. A basic discussion of changes which can occur appears in several reports concerning land disposal of wastewater (McGauhey and Krone, 1967; Drivers et al., 1972). In the following paragraphs several of the most important parameters are discussed with relation to their possible fate in the soil system. This discussion is only a summary and the references cited can be consulted for greater detail.

Nitrates. The average nitrate nitrogen concentration measured in the recharge water during the period of January through October, 1974, was 12.9 mg/l. The groundwater in the area of the recharge basins has a natural concentration that ranges between 3 and 7 mg/l. Nitrates are not readily absorbed by the soil and thus tend to move through the soil in solution. Reduction in concentration can occur by plant uptake and denitrification (Murrmann and Koutz, 1972, p. 71). A report sponsored by the Corps of Engineers (Driver et al., 1972), mentions that the removal of nitrogen by denitrification is dependent on the soil type and length of inundation of infiltration ponds, with clay soils and long inundation times promoting nitrogen removal. Based on plotted data (Driver et al., 1972, p. 93), a 10-day inundation period would remove about 35 percent of the applied nitrogen.

Nitrate uptake by plants will occur most rapidly during the dry period of the wet-dry cycle when plant growth is the most rapid in the basins. Uptake will be limited to the amount of nitrates available in the soil moisture remaining after recharging has ceased. During operation of the project the grass in the basins was frequently mowed and removed from the area.

It is probable that a combination of these two mechanisms reduced the nitrate level in the applied recharge water in Golden Grove. The chief concern with nitrates is to keep the level in water consumed by the public to below 10 mg/l as NO_3-N. This is to prevent the occurrence of methemoglobinemia in infants. Dilution of the water pumped from municipal wells in the recharge area with other sources of water contributing to the island's water supply maintains an acceptable nitrate concentration in the water supply.

Ammonia. The average ammonia-nitrogen concentration in the applied recharge water was about 7 mg/l during the period of January through October, 1974. The normal concentration in the groundwater in Golden Grove ranges up to about 0.5 mg/l.

Ammonia at a neutral pH, 6 to 7, is readily adsorbed onto clay soil particles (Murrmann and Koutz, 1972). This will act to hold the ammonia for use by plants at a generally slower rate of uptake. The effluent used in recharging generally had a pH between 6.5 and 7.0. The rapid growth of vegetation on the basins between inundation periods followed by mowing and harvesting should continue to remove ammonia from the system.

Phosphorus. The average concentration of all forms of phosphorus in the applied recharge water was about 9 mg/l as P during the period January to October, 1974. The normal concentration in the groundwater in Golden Grove ranges up to about 0.1 mg/l.

Phosphorus acts similarly to ammonia and is adsorbed in the soils especially on clay particles which are prevalent at the recharge site. The phosphorus will also be utilized by vegetation in the area and can be removed from the system through plant harvesting.

Coliforms. The level of standard coliforms in the applied effluent was very low due to the effective disinfection process at the AWWTP. The effectiveness of soils in removing bacterial pathogens is documented and discussed in detail by McGauhey and Krone (1967, pp. 70-78) and in a recent report issued by the Corps of Engineers (Driver et al., 1972, pp. 49-55). These reports mention the mechanisms of mechanical filtration and adsorption along with natural dieback of pathogens in the soil. These are especially effective in clayey and silty soils which predominate in Golden Grove.

The background data on all of the public wells in the study area show a substantial level of coliforms in many of the wells. The operation and sanitation of these wells was not under project control during this study. Many public wells on St. Croix were not sealed properly to prevent surface leakage and contamination until rather recently. Disinfection of the wells before, or during, operation is generally not practiced. Under these conditions it is not possible to correlate recharge operations with any change in coliforms in pumping wells in the area. Based on the disinfection practices used and the literature cited, it is highly doubtful that any bacterial contamination of the pumping wells did, or will, occur due to recharging operations in Golden Grove.

BOD, COD, and TOC. The water applied to the recharge basins had an average BOD of 11.5 mg/l and a COD of 30 mg/l. The ability of a soil system to reduce this oxygen demand caused by organics is discussed in many reports (McGauhey and Krone, 1967; Driver et al., 1972; Broadbent, 1973). The organic loading from the AWWTP effluent on the soil system was low. Evidence of increased organic concentrations in the monitored wells was not apparent and it is likely that the organic content was diminished due to oxidation.

In studying the results of the analysis of the monitoring wells in the study area for BOD and COD, as presented in the Appendix, two facts must be kept in mind. The first is that BOD and COD measurements at a low level of 0 to 20 mg/l are not very dependable since any minor contamination, or laboratory error, will dramatically affect the results. The second problem is that all of the pumping public wells monitored are equipped with a vertical turbine pump whose shaft bearings are lubricated by dripping oil down the space between two concentric shafts in the well. This oil, up to about 0.5 gal/month (2 l/month), accumulates and floats on the surface of the water inside the well. Depending on the level of the water in the well in relation to the pump, this oil can be intermixed with the water and pumped out of the well in varying concentrations. This, then, also has noticeable effect on TOC measurements taken on samples. Due to the circumstances of pump start-up and throttling required for the homogenation and entrance of the oil into the pumped water, it will happen at irregular times without necessarily a definite pattern being detected.

Summary of Water Quality Changes. The previous paragraphs have reviewed the possible reasons behind the water quality changes observed in the monitored pumped wells in the study area in the vicinity of the recharge facilities.

Other wells closer to the spreading basins were also sampled and tested for the same parameters during recharge operations. These were wells PW-6, PW-7, and PW-8. The primary purpose of these wells was to monitor water level information and hence they were not equipped with pumps. Samples were obtained by the use of a torpedo sampler. Although the sampler was filled several times before taking a sample for laboratory analysis the procedure did not cause much movement of water within the 8-in. (20 cm) well casing.

The monthly data for the analysis of the samples appear in the Appendix. The data do not show the changes, especially in chloride concentrations, that could be expected. This is probably due to two reasons. First the wells are believed to be located in sand lenses which are not directly connected to the main flow path of groundwater through the area. Second the wells were not pumped so that a continuous interchange of water could occur in the wells. Had continuous pumping occurred, the location of the wells away from the main path of flow would probably have been less significant. As it is, the data are included only for general background information for future studies.

WATER QUALITY IN FUTURE OPERATIONS

Once the problem of saltwater flushing in Frederiksted is resolved the artificial recharge operations can resume. If, at that time, the distribution of potable water is planned so as to transfer the low TDS desalinized water to the western end of the system, then it will result in the collection of wastewater with a low chloride concentration. Judging from the anlysis of wastewater from villages served wholly by desalinized water (Black, Crow and Eidsness, Inc., 1973, pp. 3-12), it can be expected that the wastewater will have a chloride content of about 100 to 150 mg/l.

The use of processed effluent with a low level of chlorides for recharge operations in Golden Grove should eliminate the chloride problems experienced during the project's operations in 1974. With proper extraction control, it could lead to partial restoration of the Fair Plains well field.

AWWTP OPERATIONS

The operations of the AWWTP was discussed in detail in the earlier sections. The data obtained from the operation have been tabulated and presented in a statistical format in Tables E-1 and E-2 of the Appendix.

The production of the plant which was used for recharge purposes is shown in Figure 27 and the average operating parameters in Tables 4 and 5.

These data cover the period January through October, 1974. January marked the beginning of normal operation after the start-up phase. The project ceased recharge operations during the last week of October due to the high TDS wastewater, while at the same time the heavy rains began to affect the plant performance due to excessive inflow. In early November, 1974, the flooding on the island damaged portions of the interceptors so that much of the influent to the plant consisted of the streamflow from Bethlehem Gut. During subsequent repairs of this interceptor and the one to Frederiksted, which took place over the following 6 months, flows were interrupted and/or bypassed so that normal operation of the AWWTP was not possible. In view of this, the data presented are limited to the period stated.

COST FACTORS

Cost factors, based on the operation of the AWWTP and the recharge facilities, have been projected for the production of artificially recharged groundwater. These data are shown in Table 7 and include treatment in the AWWTP, recharge operations, and groundwater recovery by wells.

Cost factors are presented for production at the present design capacity of 0.5 mgd (1,890 cu m/day) and also for expanded operation at the level of 0.75 mgd (2,840 cu m/day) and 1 mgd (3,785 cu m/day).

The information upon which the costs are determined is presented in the table along with the assumptions used. If circumstances, assumptions, or prices change; then the cost factors can be restructured within the table to arrive at a revised unit cost.

A large percentage of the total cost of reclaiming water is centered around secondary treatment. At present only primary treatment is used by the government before discharge of wastewater into the sea. If secondary treatment were required, then the cost of this portion of the facility could, in a large part, be allocated to sanitation instead of reclamation. Only the additional costs of tertiary treatment and recharging could be directly attributable to reclamation. This would then decrease the unit cost considerably in an accountant's view, although the government would continue to pay the total cost. However with secondary treatment of all wastewater before reclamation or discharge to the sea, the economies of scale would begin to reduce the unit cost of production. This is especially true in the matter of labor where the difference in staffing between a 1 mgd (3,785 cu m/day) and a 5 mgd (18,925 cu m/day) plant would not be significant. This is especially true if the recommendation to combine the management of the primary and reclamation plant is followed.

TABLE 7. PROJECTED COSTS FOR THE PRODUCTION AND RECOVERY OF RECLAIMED WASTEWATER BY GROUNDWATER RECHARGE

		AWWTP Production Capacity		
		0.5 mgd (1,890 cu m/day)	0.75 mgd (2,840 cu m/day)	1.0 mgd (3,785 cu m/day)
PRODUCTION-ANNUAL COSTS*				
I. Depreciation (20 yr straight line)				
Initial cost	$800,000	$ 40,000	$ 40,000	$ 40,000
Phase 1 Improvements†	30,000	1,500	1,500	1,500
Phase 2 Improvements†	70,000	–	3,500	3,500
Phase 3 Improvements†	140,000	–	–	7,000
Total Depreciation		41,500	45,000	52,000
II. Maintenance and repair		36,000	42,000	48,000
III. Labor				
Project director	@ $20,000/yr	20,000	20,000	20,000
Plant superintendent	@ 15,000/yr	15,000	15,000	15,000
Operator, chief	@ 10,000/yr	10,000	10,000	10,000
Operator	@ 8,500/yr	17,000	34,000	34,000
Operator, trainee	@ 7,000/yr	14,000	14,000	21,000
Chemist	@ 12,000/yr	12,000	12,000	12,000
Secretary	@ 7,000/yr	3,500	3,500	3,500
Labor Subtotal		91,500	108,500	115,500
15 percent fringe benefits		13,725	16,275	17,325
Total Labor		$105,225	$124,775	$132,825
TOTAL ANNUAL COST		$182,725	$211,775	$232,525
PRODUCTION-UNIT COSTS ($/thousand gal)				
The annual cost on a unit basis with 15 percent downtime		1.18	0.91	0.75
Coagulant-aluminum sulfate 50 mg/l at $0.10/lb ($0.22/kg)		0.042	0.063‡	0.042
Chlorine 20 mg/l at $0.25/lb ($0.55/kg)		0.042	0.042	0.042
Power		0.30	0.30	0.30
Total Production Costs		1.56	1.32	1.13
RECOVERY-UNIT COSTS ($/thousand gal)				
If 85 percent of recharged water is recovered by wells		1.85	1.55	1.34
Cost of groundwater recovery#		0.30	0.30	0.30
TOTAL COST-PRODUCTION AND RECOVERY ($/thousand gal)		2.15	1.85	1.64
($/cu m)		0.57	0.49	0.43

*Includes operation of the recharge facilities.

†See the section on project facilities for a discussion of the work involved in each phase of plant expansion.

‡Dose rate of 75 mg/l.

#Includes all costs of drilling and operating the wells.

SECTION IX

MAJOR PROBLEM AREAS ENCOUNTERED IN THE PROJECT

As in any large undertaking, there have been a considerable number of problems that have occurred during the course of the project. The vast majority of these were solvable as the project progressed. Some of them required minor changes in the direction of the project while others caused considerable delay in the completion of the project itself. The following is a discussion of some of the major problem areas within the project that became apparent as the work proceeded.

CONCEPTUAL

The reuse of water cannot be treated as an isolated event in the water resource plans of an area. The concept must be integrated into both the water supply and wastewater treatment systems. However this project was, by definition and funding, an experimental facility built to determine whether the concept was feasible. Thus major changes in the existing system and future construction could not really be expected until the feasibility was proven.

This meant that the concept of reuse had to be fitted into a system that was basically designed without that idea in mind. Since St. Croix has a variety of water sources, ranging from distilled to brackish to seawater, that feed into the wastewater system at different points; it makes it essential to coordinate the entire operation. Hence certain problems were already built, or designed, into the system and either had to be compensated for during the project or will require modification in the future.

The most notable problem resulting from this conceptual gap is the high chloride level of the incoming wastewater. In order for project operations to proceed at all, a chloride level of up to 500 mg/l had to be tolerated and used for recharge purposes. This was the result of the brackish well water that was being used in the section of the island whose wastewater supplied the project.

Even more critical is the use of seawater for fire and flushing purposes in the towns of Christiansted and Frederiksted. It was the connection of the wastewater collection network of Frederiksted, with its salty wastewater, to the central primary treatment plant that finally closed the project down in October, 1974. Although the problem in Frederiksted will be resolved, at least temporarily, in the fall of 1975, the potential chloride problem posed by the connection of Christiansted to the system in 1977 lies ahead.

COORDINATED PLANNING

There are numerous agencies within the territorial government which have an interest and responsibility for the production, distribution, and usage of public potable water plus the collection, treatment, and disposal of the island's wastewater. This split responsibility has caused confusion and occasional problems in fulfilling the project goals.

CHANGING CONDITIONS

Under actual field conditions on a project of this magnitude and time span, unwanted changing conditions had to be accepted. Many of these changes would not be tolerated in a laboratory operation where it is desirable to hold conditions the same while varying selected parameters, preferably one at a time. There were four main areas where these changing conditions caused problems.

Weather

Several extreme, and unseasonable, variations in the amount of precipitation occurred during the project. This resulted in excess groundwater during the exploratory and design phase. Then an extreme deficiency occurred during the recharge operations. The operations were finally terminated by record rains and floods that severely damaged the facilities. This has been followed by another unusual and extended drought period. These swings have affected the quality of wastewater received, the well yields, aquifer conditions, and surface-water activity.

Water Sources

The changing production levels of the various sources of water on the island affected the quality of the subsequent wastewater to a large extent. This is especially true in the western portion of the island where any reduction in the production of desalinized water from the Martin Marietta plant meant an immediate increase in the proportion of brackish well water used. This had an effect on the quality of water produced at the reclamation plant due to the change in the mineral content of wastewater received.

Construction Activity

This activity occurred both in the drainage areas tributary to the recharge area and those associated with the wastewater collection system. In the immediate area, the construction of a large penitentiary complex adjacent to the recharge area resulted in the loss of a large number of piezometers and the use of a portion of the streambed that had been planned for recharge operations.

The large amount of public housing constructed during project development which contributed its wastewater to the interceptor system changed the expected character of that wastewater. All during the project the interceptor system was being expanded. This meant that the volume of wastewater was increasing and changing as areas with different water sources were sewered.

Groundwater Extraction

The quantity of groundwater removed from the study area was varied to meet local demand or to inversely match the output of the desalinization plants. The project had no control, besides suggestive, over the operation of these wells.

PROJECT LOCATION

It was implicitly assumed that the reclamation plant would be located adjacent to the newly constructed central primary treatment plant on the island. This latter facility was located on the island with hydraulic transport and outfall disposal characteristics in mind. This location, along with the funding limitations in constructing a force main, restricted the choice of recharge areas.

DELAYS

The wide scope of the project made it extremely vulnerable to delays due to complications in some stage of either this project or one of the many other activities that affected this project. The most significant delays are discussed in the following paragraphs.

The completion of the interceptor sewers was delayed in schedule, which greatly reduced the amount of wastewater that the project had available to process and reuse. This delay has to be weighed against the benefit of not completing the Frederiksted pumping station on time. It permitted the operation of the recharge phase without the flow of salt water that accompanied the Frederiksted wastewater.

The construction of the AWWTP was delayed due to shipment and procurement problems with some of the proprietary devices, problems with subcontractors, and construction difficulties.

The shipment of spare parts for the repair of equipment was often delayed during plant operation. The customs status of the territory and the distance between the mainland United States and the Virgin Islands caused numerous difficulties in obtaining spare parts and manufacturers' service. Airfreighting of shipments was no guarantee that they would arrive in a reasonable time. Most spare parts were unavailable locally.

EQUIPMENT OUTAGES

Problems were experienced with several pieces of equipment in the AWWTP. These were mainly pumps which required numerous repairs. During the periods when these pumps were out of service, the production of the AWWTP was reduced, often to no usable output at all.

NATURAL DISASTERS

Flooding occurred on the island during October and November in 1974, seriously damaging the recharge facility and necessitating extensive repairs to the basins, roadways, and pipelines. The floods also damaged the primary treatment plant and many of the major wastewater interceptors so that the amount of wastewater supplied to the AWWTP was severely restricted for several months and that which was received was difficult to handle due to the high percentage of clay it contained.

SUMMARY

Despite all of these problems experienced during the project and all those that will occur during its future operation, the economics of the system will make it worthwhile to continue. The cost of fresh water is too high on St. Croix to use it only once and throw it away.

SECTION X

OTHER ACTIVITIES ASSOCIATED WITH THE WASTEWATER RECLAMATION PROJECT

Although the purpose of the project was to determine the feasibility of artificial groundwater recharge, it did encourage other uses for reclaimed wastewater. The purpose of this was two-fold; first, to explore alternative uses for treated wastewater. This is especially important if these alternative uses can replace potable water, which is both expensive and in short supply on the island. Secondly, it was a means of encouraging community-wide interest and support for the idea of wastewater reclamation and water reuse. If another organization or agency actually worked with water reuse and was successful, then it could mean more support for the continuance of the project once the local government assumed operations. The project personnel were successful in encouraging other people to experiment with the reclaimed water and several of these activities are discussed below.

IRRIGATION

One of the biggest hindrances to the development of a sound agricultural industry on St. Croix, in the area of fruits and vegetables, is the lack of water. A large amount of water is needed in agriculture to counteract the excessive evapotranspiration rate caused by the high ambient temperature and steady tradewinds. Only a week without water can severely damage many vegetable crops on the island. Rainfall has traditionally been extremely unreliable in its time patterns on the island. The rainfall pattern in the last three years has been such that a vegetable enterprise without supplemental irrigation would have faced disaster. Unfortunately, the potable water is too expensive, at $1,300/acre-ft ($1.05/cu m), to be used; the groundwater is limited in quantity; and in many areas the groundwater's sodium absorption ratio (SAR) and/or chloride content is too high for prolonged use.

Reclaimed wastewater with a controlled SAR and chloride level could be used, in many cases, for agricultural irrigation. Initial uncontrolled experiments were carried out in this area by personnel at the AWWTP in growing ornamental plants and vegetables in a small nursery. Chlorinated effluent from the AWWTP was used for the necessary irrigation. This was an extremely effective public relations feature for the project. If visitors could not fully comprehend the workings of the biological and chemical treatments going on within the AWWTP, they could easily appreciate the profusion of flowers and vegetables that were grown with the finished product. This was especially true since the rest of the island was parched and brown due to one of the longest droughts in recent times.

This created sufficient interest that a cooperative venture by the V.I. Extension Service and the V.I. Experiment Station financed and built a 3,000-ft (915 m) spur line that will permit the transfer of reclaimed wastewater directly to the St. Croix campus of the College of the Virgin Islands. There it will be used for research into the uses and effectiveness of irrigation under the subtropical conditions existing in the territory. This research activity was halted due to the high chloride content in the wastewater but is expected to resume in the fall of 1975.

CLAM CULTURE

Using the nutrients available in the wastewater effluent from the AWWTP, a project to culture freshwater clams (Rangia cuneata) has been started. This project is under the direction of the biological oceanography section of the Lamont-Doherty Geological Observatory of Columbia University. It has a facility on St. Croix which has been conducting research on the use of ocean nutrients for production of shellfish for the past 6 years. The clam operation is quite similar in that it utilizes the nutrients remaining in the wastewater effluent to grow algae which are fed to clams. Presently the clam-raising facilities, which are actually large chemostats, have been constructed on the grounds of the AWWTP and began operations in August, 1975. The first phase consists of stabilizing the algal growth in the chemostats. Extensive preliminary tests have already been run at the Columbia University laboratory in St. Croix to select the algae strains to be used and to approximate the growth rate to be expected.

The ultimate purpose of the clams will be to use them for a protein source for poultry on the island. When the clams reach the desired size, both the meat and shells will be ground up and the mixture fed to chickens.

PISCICULTURE

This project also uses the nutrients in the effluent of the AWWTP to grow algae. In this case it will be used to grow Talapia aurea which are a freshwater herbivorous food fish.

This project is sponsored primarily by the V.I. Agricultural Experiment Station. Four ponds have been constructed in the vicinity of the recharge area in Estate Golden Grove and fish are being raised in one of them. Each of these ponds has a capacity of about 0.1 mil gal (380 cu m). The fish will grow in cages suspended in the water. The effluent from the ponds will be used for irrigation purposes. It is proposed that these fish will be used for human consumption.

INTERRELATIONSHIP

In addition to these three activities involving water reuse that have been developed in cooperation with the wastewater reclamation project, other projects have been suggested by local groups and citizens interested in utilizing this valuable resource. Many of these additional suggestions require further definition and sound financing. The local government, in cooperation with the Water Resources Research Center in St. Thomas, is developing better guidelines and regulations applicable to wastewater reclamation and reuse.

Since water is precious in the territory, all of these activities help to complete the water resources picture on St. Croix. Figure 43 shows the interrelationships between the existing water sources and the reclamation project with all of its various associated activities.

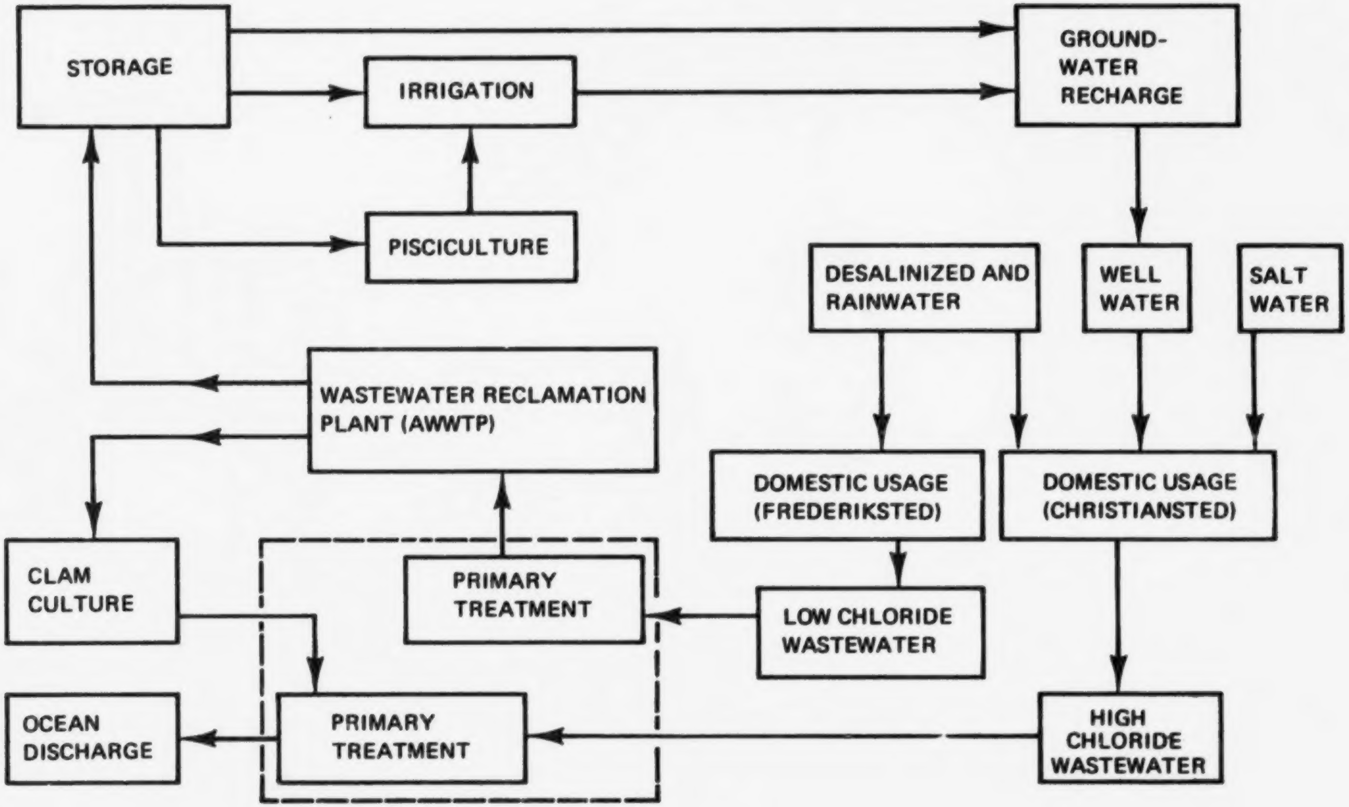

STORAGE
IRRIGATION
GROUND-WATER RECHARGE
PISCICULTURE
DESALINIZED AND RAINWATER
WELL WATER
SALT WATER
WASTEWATER RECLAMATION PLANT (AWWTP)
DOMESTIC USAGE (FREDERIKSTED)
DOMESTIC USAGE (CHRISTIANSTED)
CLAM CULTURE
PRIMARY TREATMENT
LOW CHLORIDE WASTEWATER
OCEAN DISCHARGE
PRIMARY TREATMENT
HIGH CHLORIDE WASTEWATER

Figure 43. Proposed interrelationships between water use and reuse activities on St. Croix.

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APPENDIX

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	Part A contains the drilling logs of the nine wells which were constructed as part of the project. The locations of these wells are shown in Figure 16.	
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	Part B contains monthly data on the analysis of water samples taken from the primary wells monitored during the project. Data for the period April through September, 1975, are furnished through the courtesy of the Caribbean Research Institute of the College of the Virgin Islands. The locations of these wells are shown in Figure 16.	
C	SECONDARY WELLS--ANALYTICAL DATA	178
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F SOIL BORING INFORMATION 208

Part F contains a figure showing the driller's logs of the soil borings taken in the Golden Grove area.

G WATER LEVELS IN PROJECT WELLS 210

Part G contains graphs of the water levels in various wells in relation to the amount of rainfall. The locations of these wells are shown in Figure 16.

H ENGLISH-TO-METRIC CONVERSION 244

In recognition of the advance of the United States to the metric system, the text of this report is written with metric equivalents following the English units of measurement. To avoid confusion and space problems some of the tables and illustrations do not have these equivalents. The following table is a list of English units used and their metric equivalents to assist in making individual conversions. The standard abbreviations for the respective units are used.

APPENDIX - PART A

TABLE A-1. LOG FOR PROJECT WELL NO. 1 (PW-1)

Description	Thickness of strata ft	Depth of strata* ft	Elevation of strata† ft
Alluvium			
Topsoil	2	2	51
Silty clay	13	15	38
Clayey sand trace gravel and silt, water encountered at elevation 33 ft	9	24	29
Sandy silty clay trace gravel	3	27	26
Clayey silty gravel (water bearing)	4	31	22
Silty clay	4	35	18
Clayey sand with gravel (water bearing)	3	38	15
Silty clay trace sand & gravel	10	48	5
Sandy gravel trace clay (water bearing)	4	52	1
Clayey silty gravel (water bearing)	2	54	-1
Silty clay	6	60	-7
Clay trace silt	7	67	-14
Kingshill marl			
White limestone, seashells	9	76	-23

Casing perforations:	3 slots/ft	15 - 25
	3 slots/ft	28 - 32
	3 slots/ft	35 - 40
	3 slots/ft	48 - 55
	3 slots/ft	68 - 74

Well location: Golden Grove
Casing used: 8 in. steel - 78 ft
First encountered water at elevation: 33 ft

Date drilled: July 1972
Ground elevation: 53 ft

Test pumping of aquifer located at elevation -1 ft yielded 13 gpm in August 1972. The combined aquifers were pumped at 45 gpm.

Static water level in August 1972 was at elevation 41 ft.

Feet x 0.3048 = meters

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*Depth to bottom of strata.
†Elevation of the bottom of the strata.

TABLE A-2. LOG FOR PROJECT WELL NO. 2 (PW-2)

Description	Thickness of strata ft	Depth of strata* ft	Elevation of strata† ft
Kinghill marl			
Topsoil	2	2	74
White stratified limestone (dry)	77	79	-3
White limestone, very hard layer Encountered water just below hard layer	1	80	-4
White limestone stratified	20	100	-24

Casing perforations:		
	1 1/2 slots/ft	30 - 65
	3 1/2 slots/ft	65 - 95

Well location: Negro Bay
Casing used: 8 in. steel - 103 ft
First encountered water at elevation: -4 ft

Date drilled: July 1972
Ground elevation: 76 ft

In August 1972, the well was test pumped at 60 gpm (limit of the pump).

The static water level in August 1972, was at elevation 14 ft.

Feet x 0.3048 - meters

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*Depth to bottom of strata.
†Elevation of the bottom of the strata.

TABLE A-3. LOG FOR PROJECT WELL NO. 3 (PW-3)

Description	Thickness of strata ft	Depth of strata* ft	Elevation of strata† ft
Kingshill marl			
Topsoil	2	2	76
White stratified limestone	77	79	-2
White limestone, very hard layer Encountered water just below hard layer	1	80	-3
White limestone soft	72	152	-75
Jealousy Formation			
Blue clay	3	155	-78

Casing - only an 8 ft piece of casing at the top of the well. Supported by angle iron at the surface.

Well location: Negro Bay
Casing used: 8 in. steel - 8 ft
First encountered water at elevation: -3 ft
Date drilled: July 1972
Ground elevation: 77 ft

In August 1972, the well was test pumped at 2 gpm when 100 ft deep and again at 2 gpm when 155 ft deep.

The static water level in August 1972 was at elevation 33 ft.

Feet x 0.3048 = meters

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*Depth to bottom of strata.
†Elevation of the bottom of the strata.

TABLE A-4. LOG FOR PROJECT WELL NO. 4 (PW-4)

Description	Thickness of strata ft	Depth of strata* ft	Elevation of strata† ft
Alluvium			
Silty clay	5	5	45
Silty clay with angular gravel	5	10	40
Sandy clayey gravel	4	14	36
Gravel, encountered water	1	15	35
Sandy gravel	3	18	32
Clay with some gravel	4	22	28
Clay, very hard layer at depth 27-28 ft	6	28	22
Sandy clay with a trickle of water	7	35	15
Sandy gravel trace clay (water bearing)	2	37	13
Clay trace gravel	13	50	0
Clay, hard layer	5	55	-5
Kingshill marl			
White soft marl	21	76	-26
White stratified limestone	4	80	-30
White soft marl	30	110	-60

Casing - only the top 62 ft of the well is cased. Perforations are as follows:

7 slots/ft	13 - 18
7 slots/ft	33 - 43
7 slots/ft	56 - 61

Well location: Golden Grove
Casing used: 8 in. steel - 65 ft
First encountered water at elevation: 36 ft

Date drilled: July 1972
Ground elevation: 50 ft

In August 1972 the well was test pumped at 25 gpm when 65 ft deep and at 27 gpm when 110 ft deep.

The static water level in August 1972 was at elevation 39 ft.

Feet x 0.3048 = meters

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*Depth to bottom of strata.
†Elevation of the bottom of the strata.

TABLE A-5. LOG FOR PROJECT WELL NO. 5 (PW-5)

Description	Thickness of strata ft	Depth of strata* ft	Elevation of strata† ft
Alluvium			
Silty clay	8	8	47
Silty clay trace sand	4	12	43
Silty clay trace gravel	6	18	37
Clayey sandy silt trace gravel	2	20	35
Sandy clayey gravel, trickle of water at elevation 30 ft	7	27	28
Clayey gravel	3	30	25
Sandy silty clay trace gravel, sticky	2	32	23
Sandy clay trace gravel, hard layer	6	38	17
Sandy clay trace gravel	2	40	15
Casing perforations: 7 slots/ft		20 - 27	
7 slots/ft		33 - 40	

Well location: Golden Grove
Date drilled: August 1972
Casing used: 6 in. PVC - 42 ft
Ground elevation: 55 ft
First encountered water at elevation: 30 ft

In August 1972 the well was test pumped at less than 5 gpm.

The static water level in August 1972 was elevation 34 ft.

Feet x 0.3048 = meters

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*Depth to bottom of strata.
†Elevation of the bottom of the strata.

TABLE A-6. LOG FOR PROJECT WELL NO. 6 (PW-6)

Description	Thickness of strata ft	Depth of strata* ft	Elevation of strata† ft
Alluvium			
Clay	5	5	43
Sandy clay trace gravel	5	10	38
Clay, very sticky	2	12	36
Sandy clay trace gravel	8	20	28
Clay, very fine smooth	7	27	21
Sandy clay trace gravel	3	30	18
Sandy clay trace gravel, trickle of water at elevation 17 ft	4	34	14
Sandy gravelly clay	1	35	13
Clay, sticky	4	39	9
Casing perforations: 7 slots/ft		21 - 39	

Well location: Golden Grove
Casing used: 8 in. steel - 42 ft
First encountered water at elevation: 17 ft

Date drilled: August 1973
Ground elevation: 48 ft

The well was moist but had no water in August 1973.

The static water level in May 1975 was at elevation 25 ft.

Elevation to top of casing is 51 ft. The casing was buried to the top edge during construction of the fish ponds in 1973.

Feet x 0.3048 = meters

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*Depth to bottom of strata.
†Elevation of the bottom of the strata.

TABLE A-7. LOG FOR PROJECT WELL NO. 7 (PW-7)

Description	Thickness of strata ft	Depth of strata* ft	Elevation of strata† ft
Alluvium			
Clay	3	3	44
Clayey sand	2	5	42
Sandy clay	7	12	35
Gravelly clayey sand	2	14	33
Sandy clay, sticky	1	15	32
Sandy silty clay, sticky	5	20	28
Casing perforations: 7 slots/ft		1 - 20	

Well location: Golden Grove
Date drilled: August 1973
Casing used: 8 in. steel - 21 ft
Ground elevation: 47 ft
First encountered water at elevation: None encountered

The well was moist but had no water in August 1973.

The static water level in February 1975 was elevation 31 ft.

Feet x 0.3048 = meters

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*Depth to bottom of strata.
†Elevation of the bottom of the strata.

TABLE A-8. LOG FOR PROJECT WELL NO. 8 (PW-8)

Description	Thickness of strata ft	Depth of strata* ft	Elevation of strata† ft
Alluvium			
Clay trace sand	5	5	42
Sandy clay trace gravel	5	10	37
Sandy gravelly clay	2	12	35
Sandy clay	2	14	33
Clay trace sand	5	19	28
Clayey gravel	3	22	25
Clayey sand, trickle of water at elevation 24 ft	6	28	19
Clay	2	30	17
Casing perforations: 7 slots/ft		8 - 12	
7 slots/ft		19 - 29	

Well location: Golden Grove
Casing used: 8 in. steel - 33 ft
First encountered water at elevation: 24 ft

Date drilled: August 1973
Ground elevation: 47 ft

The well had no water in August 1973.

The static water level in January 1975 was at elevation 35 ft.

Feet x 0.3048 = meters

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*Depth to bottom of strata.
†Elevation of the bottom of the strata.

TABLE A-9. LOG FOR PROJECT WELL NO. 9 (PW-9)

Description	Thickness of strata ft	Depth of strata* ft	Elevation of strata† ft
Alluvium			
Clay trace sand	8	8	41
Clayey sand trace gravel	7	15	34
Clayey sand	2	17	32
Sandy clay	3	20	29

Casing - The elevation 29 to 41, an 8 in. steel casing is used. This is slotted 10 shots/ft in its upper 6 ft. Above this is a 2 in. galvanized pipe which goes to the surface. At the connection of the two is a concrete seal. The purpose of the well was to test the feasibility of an injection well.

Well location: Golden Grove
Date drilled: August 1973
Casing used: See above
Ground elevation: 49 ft
First encountered water at elevation: No flow encountered

The well was moist but had no water in August 1973.

The static water level in February 1975 was at elevation 33 ft.

Feet x 0.3048 = meters

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*Depth to bottom of strata.
†Elevation of the bottom of the strata.

TABLE B-1. ANALYSIS OF SAMPLES TAKEN FROM WELL A-16

Date		Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total Hardness mg/l as CaCO$_3$	Ca mg/l as CaCO$_3$	Mg mg/l as CaCO$_3$	CO$_3$ mg/l as CaCO$_3$	HCO$_3$ mg/l as CaCO$_3$	NO$_3$-N mg/l	NO$_2$-N mg/l	NH$_3$-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1971	Jul	–	1,500	–	–	–	0	–	–	–	–	–	–	–	–	–
	Aug	145	1,420	254	78	176	0	523	–	–	–	–	–	–	–	–
	Sep	170	1,400	272	100	172	0	530	–	–	–	–	–	–	–	–
	Oct	160	1,480	252	108	144	0	575	–	–	–	–	–	–	–	–
	Nov	–	–	–	–	–	0	576	–	–	–	–	–	–	–	–
	Dec	145	1,500	272	112	160	0	568	–	–	–	–	–	–	–	0
Mean		153	1,441	262	103	159	0	554	–	–	–	–	–	–	–	–
Std Dev		10	40	10	12	12	0	26	–	–	–	–	–	–	–	–
1972	Jan	200	1,300	260	112	148	0	576	–	–	–	–	–	–	–	10
	Feb	160	1,430	280	100	180	0	584	–	–	–	–	–	–	–	–
	Mar	150	1,450	280	120	160	0	568	–	–	–	–	–	–	–	6
	Apr	150	1,450	288	108	180	0	576	–	–	–	–	–	–	–	9
	May	150	1,400	268	112	156	0	572	–	–	–	–	–	–	–	–
	Jun	120	1,400	276	88	188	0	568	–	–	–	–	–	–	–	–
	July	120	1,400	280	88	192	0	564	–	<1	0.36	0.027	–	–	–	–
	Aug	150	1,400	272	92	180	0	568	–	<1	0.37	0.037	–	–	30	–
	Sep	180	1,400	272	92	180	0	564	–	<1	0.34	0.033	–	–	2.6	–
	Oct	180	1,400	272	100	172	0	568	–	<1	0.40	0.035	–	–	–	–
	Nov	170	1,400	268	100	168	0	560	4.1	<1	0.39	0.025	–	–	–	–
	Dec	150	1,400	268	100	168	0	564	3.8	<1	0.40	0.040	–	–	–	–
Mean		163	1,320	274	100	174	0	569	4.0	–	0.38	0.03	–	–	16.3	–
Std Dev		24	324	10	9	12	0	7	0.2	–	0.02	0.01	–	–	19.4	–
1973	Jan	150	1,300	284	104	180	0	560	3.9	<1	0.42	0.035	–	–	8	–
	Feb	145	1,400	262	88	174	0	600	–	–	–	–	–	–	–	–
	Mar	150	1,400	260	104	156	0	536	–	–	0.81	0.029	–	–	16	0
	Apr	160	1,400	284	116	168	0	516	2.8	0.010	–	0.035	–	–	–	0
	May	180	1,400	280	112	168	0	527	3.1	0.004	0.46	0.060	–	<5	12	0
	Jun	180	1,300	272	108	164	0	536	2.7	–	0.47	0.134	–	<5	–	1

TABLE B-1 (CONTINUED).

Date	Chlorides mg/l	Conductivity µmhos/cm² at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1973 Jul	200	1,400	280	120	140	0	556	3.6	–	0.13	0.022	–	–	–	0
Aug	170	1,500	304	112	192	0	520	3.3	<0.001	0.46	0.032	–	<5	5	>100
Sep	170	1,500	–	–	–	–	–	3.2	–	0.43	0.084	–	–	–	0
Oct	170	1,400	288	126	142	0	524	–	–	–	–	–	<5	–	0
Nov	150	1,300	260	104	156	0	512	2.9	<0.001	0.04	0.026	<5	–	.49	0
Dec	170	1,400	260	100	160	0	504	3.8	0.001	0.06	0.042	<5	<5	–	0
Mean	170	1,385	276	108	166	0	536	3.2	–	0.36	0.05	–	–	8.3	–
Std Dev	33	61	13	10	15	0	27	0.4	–	0.25	0.03	–	–	6.0	–
1974 Jan	180	1,350	300	112	188	0	528	3.4	<0.001	<0.01	0.042	6	<5	–	0
Feb	160	1,400	256	68	188	0	496	3.2	<0.001	0.04	0.048	<5	<5	5	1
Mar	160	1,300	272	100	172	0	532	3.0	–	–	0.034	–	<5	–	1
Apr	–	–	–	–	–	0	–	–	–	0.07	0.033	–	–	–	–
May	130	1,400	260	96	164	0	530	3.5	<0.001	0.23	0.032	<5	<5	6	34
Jun	170	1,400	256	80	176	0	536	3.6	<0.001	0.19	0.056	5	6	–	0
July	170	1,300	248	104	144	0	416	3.4	0.001	0.28	0.031	<5	<5	15	12
Aug	170	1,200	248	100	148	0	516	3.3	0.002	0.22	0.028	<5	–	–	2
Sep	170	1,200	260	92	168	0	516	3.3	–	<0.01	0.063	<5	–	–	0
Oct	180	1,300	260	96	164	0	508	–	0.002	–	0,046	<5	–	–	0
Nov	–	–	–	–	–	–	–	–	0.009	–	0.037	<5	–	–	–
Dec	170	1,300	–	–	–	–	–	3.3	–	–	–	–	–	–	–
1975 Jan	170	1,300	–	–	–	–	–	3.6	0.001	0.24	0.050	11	–	–	–
Feb	170	1,300	260	108	152	0	524	–	0.004	0.32	–	–	–	–	1
Mar	210	1,350	–	–	–	–	–	3.2	–	0.17	0.042	<5	–	–	–
Apr	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
May	190	1,300	–	–	–	–	–	3.8	–	0.15	0.230	–	–	–	–
Jun	190	1,400	272	97	175	0	524	–	0.002	0.12	–	–	–	–	3
July	175	1,300	–	–	–	–	–	3.2	0.002	0.10	0.030	–	–	–	–
Aug	180	1,300	345	76	269	0	513	3.7	0.001	–	0.029	–	–	–	0
Sep	180	1,300	–	–	–	–	–	3.4	0.002	0.10	0.023	–	–	–	–

TABLE B-2. ANALYSIS OF SAMPLES TAKEN FROM WELL BMW-3

Date		Chlorides mg/l	Conductivity µmhos/cm² at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P* mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1972	Oct	520	2,800	260	100	160	0	640	–	–	–	–	–	–	–	–
1973	Feb	510	2,800	254	120	134	0	696	–	–	–	–	–	–	–	–
	Mar	530	3,000	264	124	130	0	616	–	–	0.78	–	–	–	–	0
	Apr	570	2,800	256	140	116	0	596	4.2	–	0.19	–	–	–	–	0
	May	600	3,000	288	144	144	0	588	5.4	0.004	0.56	–	–	<5	17	–
	Jun	580	2,800	280	140	140	0	620	–	–	0.56	–	–	<5	10	0
	July	600	2,800	284	128	156	0	620	5.1	0.003	0.29	–	–	<5	–	0
	Aug	490	2,600	268	128	140	0	596	4.1	0.001	0.42	–	–	<5	3	–
	Sep	470	2,800	–	–	–	–	–	4.7	–	0.53	–	–	–	–	0
	Oct	550	3,000	280	132	148	0	616	5.3	–	0.13	–	–	<5	–	0
	Nov	560	2,600	288	132	156	0	600	5.0	<0.001	0.05	–	<5	<5	12	0
	Dec	550	2,800	300	132	168	0	592	5.3	0.003	0.14	–	<5	<5	5	0
Mean		546	2,318	275	132	143	0	614	4.9	–	0.37	–	–	–	9.4	–
Std Dev		43	140	17	8	15	0	31	0.5	–	0.24	–	–	–	5.6	–
1974	Jan	600	2,800	296	156	140	0	624	4.6	0.001	<0.01	–	<5	<5	–	0
	Feb	580	2,800	308	140	168	0	624	4.4	<0.001	0.19	–	<5	<5	5	0
	Mar	610	2,800	304	152	252	0	624	4.9	0.001	–	–	–	<5	–	0
	Apr	–	–	–	–	–	0	–	–	–	0.09	–	–	–	–	–
	May	590	3,000	276	132	144	0	612	4.4	0.002	0.18	–	<5	<5	5.9	0
	Jun	580	3,000	280	132	148	0	608	5.2	0.002	0.23	–	<5	<5	–	0
	July	590	2,700	272	136	136	0	616	5.1	<0.001	0.20	–	<5	<5	–	0
	Aug	610	2,600	–	–	–	–	–	5.4	0.002	0.17	–	5	–	–	–
	Sep	570	2,200	296	140	156	0	596	5.2	0.002	0.12	–	<5	–	–	0
	Oct	560	2,400	272	136	136	0	586	4.4	0.002	0.33	–	7	–	–	0
	Nov	–	–	–	–	–	–	–	–	0.003	–	–	<5	–	–	–
	Dec	530	2,400	–	–	–	–	–	3.4	–	–	–	–	–	–	–
1975	Jan	590	2,600	308	140	168	0	608	4.8	0.001	–	–	5	<5	–	0
	Feb	600	2,600	308	140	168	0	624	5.2	0.002	0.26	–	23	–	–	11

TABLE B-2 (CONTINUED).

Date	Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P* mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1975 Mar	600	2,600	-	-	-	0	-	5.1	-	0.13	-	<5	-	-	-
Apr	580	2,600	310	124	186	0	604	-	-	-	-	-	-	-	0
May	600	2,600	306	136	170	0	588	5.0	0.001	0.14	-	-	-	-	-
Jun	600	2,800	314	148	166	0	596	-	0.003	0.13	-	-	-	-	0
July	588	2,800	-	-	-	-	-	5.0	0.002	0.12	-	-	-	-	-
Aug	538	2,800	-	-	-	-	-	4.2	0.002	0.09	-	-	-	-	-
Sep	540	2,600	-	-	-	-	-	1.3	-	0.09	-	-	-	-	-

*Not measured since phosphates are added to water at the well by the owner.

TABLE B-3. ANALYSIS OF SAMPLES TAKEN FROM WELL BMW-4

Date	Chlorides mg/l	Conductivity µmhos/cm² at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1972 Jul	250	1,700	236	112	124	0	536	–	–	–	–	–	–	–	–
Oct	230	1,700	240	132	108	0	548	–	–	–	–	–	–	–	–
1973 Mar	280	1,900	204	92	112	0	556	–	–	0.80	0.080	–	–	–	0
Apr	420	2,200	208	96	102	0	592	3.1	<0.010	0.06	0.120	–	–	–	0
May	440	2,400	–	–	–	0	–	4.4	0.004	0.06	0.086	–	–	–	–
Jun	440	2,300	192	92	100	0	620	–	–	–	–	–	<5	–	0
Jul	440	2,400	196	92	104	0	600	4.8	0.001	0.13	–	–	–	–	0
Aug	–	–	200	96	104	0	612	–	–	0.27	–	–	–	–	0
Mean	404	2,240	200	94	104	0	596	4.1	–	0.26	0.20	–	–	–	–
Std Dev	70	207	6	2	5	0	25	0.9	–	0.31	0.25	–	–	–	–
WELL INOPERATIVE SEPT 1973–APRIL 1974															
1974 May	410	2,400	180	84	96	0	620	3.4	0.001	0.19	0.046	<5	<5	–	2
Jun	440	2,600	192	88	104	0	628	4.6	0.003	0.20	0.073	<5	<5	–	0
Jul	360	2,000	188	96	92	0	592	4.4	0.003	0.18	0.066	–	<5	–	1
Aug	410	2,000	188	76	112	0	616	4.5	0.002	0.21	0.066	<5	–	–	0
Sep	340	1,700	212	80	132	0	576	–	0.001	0.17	0.070	<5	–	–	0
Oct	430	2,200	208	84	124	0	612	4.3	0.002	0.17	0.110	<5	–	–	–
Nov	–	–	–	–	–	–	–	–	0.002	–	–	<5	–	–	–
Dec	400	2,000	–	–	–	–	–	3.7	–	–	0.080	–	–	–	–
1975 Jan	400	2,200	188	76	112	0	616	3.8	0.031	0.22	0.085	17	<5	–	5
Feb	390	2,100	192	96	96	0	620	4.2	0.002	0.30	0.085	5	–	–	3
Mar	400	2,200	–	–	–	–	–	3.9	–	0.21	0.074	<5	–	–	–
Apr	340	2,200	217	85	132	0	580	–	–	–	–	–	–	–	0
May	390	2,200	196	90	106	0	596	4.0	0.001	0.14	0.070	–	–	–	–
Jun	380	2,200	202	85	117	0	600	–	0.002	0.08	0.077	–	–	–	0
WELL INOPERATIVE JULY 1975–SEPTEMBER 1975															

TABLE B-4. ANALYSIS OF SAMPLES TAKEN FROM WELL BMW-5

Date	Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1973 Jul	340	2,500	320	104	216	0	720	–	–	–	–	–	<5	–	–
Aug	–	–	–	–	–	0	–	0.9	0.016	0.18	0.098	–	<5	9	>100
Sep	330	2,600	–	–	–	0	–	1.2	–	0.47	0.128	–	–	–	>100
Oct	290	2,600	384	176	208	0	804	3.0	–	–	0.136	–	<5	–	>100
Nov	320	2,400	396	184	212	0	784	2.8	0.002	0.19	0.114	<5	<5	17	5
Dec	350	2,400	392	176	216	0	748	2.5	0.004	0.11	0.122	<5	<5	6	0
Mean	326	2,500	373	160	213	0	764	2.1	–	0.24	0.120	–	–	11	–
Std Dev	23	100	36	38	4	0	37	.1	–	0.16	0.010	–	–	6	–
1974 Jan	360	2,400	412	172	240	0	780	2.0	0.004	0.04	0.095	5	<5	–	0
Feb	340	2,200	352	172	180	0	692	1.9	0.001	0.04	0.120	<5	<5	5	0
Mar	360	2,200	328	160	148	0	676	0.9	0.002	–	0.116	<5	<5	–	0
Apr	–	–	–	–	–	0	–	–	–	<0.01	–	–	–	–	–
May	390	2,400	324	158	166	0	688	–	0.002	0.23	–	<5	<5	6.31	0
Jun	400	2,600	328	148	180	0	708	–	0.002	0.17	–	9	<5	–	0
Jul	410	2,200	332	160	172	0	688	1.2	0.002	0.19	0.145	<5	<5	7	0
Aug	420	2,200	344	168	176	0	680	1.4	0.005	0.19	0.160	8	–	–	0
Sep	350	2,000	336	140	166	0	692	–	0.003	0.24	0.144	8	–	–	10
Oct	460	2,200	348	160	188	0	696	6.0	0.002	0.30	0.168	<5	–	–	0
Nov	190	1,600	–	–	–	0	–	–	–	–	–	–	–	–	–
Dec	–	–	–	–	–	0	–	5.4	–	–	0.150	–	–	–	–
1975 Jan	320	2,200	380	132	248	0	760	5.0	0.003	0.38	0.160	15	–	–	4
Feb	330	2,100	380	142	238	0	736	5.0	0.003	0.45	0.144	13	<5	–	1
Mar	–	–	–	–	–	0	–	4.3	–	0.18	0.125	<5	–	–	–
Apr	350	2,200	365	140	225	0	696	–	–	–	–	–	–	–	51
May	360	2,200	388	167	221	0	716	3.5	0.005	0.16	0.118	–	–	–	–
Jun	380	2,200	377	175	202	0	708	–	0.021	0.19	0.122	–	–	–	10
Jul	396	2,400	–	–	–	0	–	4.2	0.128	0.12	0.125	–	–	–	–
Aug	420	2,400	373	159	214	0	680	2.6	0.024	0.14	0.118	–	–	–	0
Sep	–	–	–	–	–	0	–	2.7	0.002	0.08	0.117	–	–	–	–

TABLE B-5. ANALYSIS OF SAMPLES TAKEN FROM WELL FP-5

Date	Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2 N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1971 Jul	-	4,100	-	-	-	0	-	-	-	-	-	-	-	-	-
Aug	1,035	4,200	675	336	339	0	488	-	-	-	-	-	-	-	-
Sep	940	3,900	580	308	272	0	508	-	-	-	-	-	-	-	-
Oct	1,090	4,200	856	372	484	0	545	-	-	-	-	-	-	-	20
Nov	1,060	3,700	680	372	308	0	516	-	-	-	-	-	-	-	-
Dec	1,070	4,100	704	356	348	0	528	-	-	-	-	-	-	-	0
Mean	1,039	4,033	699	348	350	0	517	-	-	-	-	-	-	-	-
Std Dev	59	197	100	27	81	0	21	-	-	-	-	-	-	-	-
1972 Jan	1,090	4,000	700	364	336	0	524	-	-	-	-	-	-	-	>100
Feb	1,120	4,100	692	376	316	0	524	-	-	-	-	-	-	-	-
Mar	1,050	4,000	-	-	-	0	-	-	-	-	-	-	-	-	6
Apr	1,100	3,900	704	368	336	0	540	-	-	-	-	-	-	-	>100
May	1,100	4,200	740	372	368	0	520	-	-	-	-	-	-	-	-
Jul	1,150	4,000	740	368	372	0	528	-	<1	0.49	0.020	-	-	17	-
Aug	1,130	3,000	760	364	396	0	528	-	<1	0.47	0.047	-	-	-	-
Sep	1,160	4,000	748	380	368	0	532	-	<1	0.49	0.047	-	-	28	-
Oct	1,120	4,000	769	384	385	0	520	-	<1	0.52	0.041	-	-	-	-
Nov	800	3,000	464	248	216	0	544	-	<1	0.49	0.033	-	-	9.2	-
Dec	980	3,500	672	300	372	0	540	4.7	<1	0.43	0.047	-	-	5.5	-
Mean	1,073	3,791	699	352	347	0	530	-	-	0.48	0.040	-	-	15	-
Std Dev	103	428	88	44	52	0	9	-	-	0.03	0.010	-	-	10	-
1973 Jan	980	3,500	684	272	412	0	540	4.8	<1	0.48	0.055	-	-	21	-
Feb	995	4,000	714	368	346	0	556	-	-	-	-	-	-	-	-
Mar	1,090	4,000	780	408	372	0	504	3.1	-	0.80	0.042	-	-	-	>100
Apr	1,230	4,000	836	456	380	0	480	4.1	<0.01	0.22	0.018	-	-	-	>100
May	1,360	4,250	976	504	472	0	488	3.8	0.004	0.67	0.064	-	<5	15	0
Jun	1,460	4,500	1,036	528	508	0	496	3.4	-	0.22	0.082	-	<5	-	>100

TABLE B-5 (CONTINUED).

Date	Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as CaCO$_3$	Ca mg/l as CaCO$_3$	Mg mg/l as CaCO$_3$	CO$_3$ mg/l as CaCO$_3$	HCO$_3$ mg/l as CaCO$_3$	NO$_3$-N mg/l	NO$_2$-N mg/l	NH$_3$-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
Jul	1,460	5,000	1,032	516	516	0	484	4.0	0.003	0.23	0.038	–	–	8	0
Aug	1,540	5,000	1,160	596	564	0	468	5.8	<0.001	0.46	0.040	–	<5	2	7
Sep	1,530	5,000	–	–	–	0	–	3.7	–	0.49	0.068	–	–	–	>100
Oct	1,600	5,000	1,220	616	604	0	464	4.0	–	0.18	0.048	–	<5	–	C*
Nov	1,710	5,000	1,304	652	652	0	468	–	0.002	0.33	–	<5	<5	11	C
Mean	1,350	4,477	974	492	483	0	494	4.1	–	0.41	0.050	–	–	11	–
Std Dev	261	553	216	118	105	0	32	0.8	–	0.21	0.020	–	–	7	–
1974 Jan	1,610	5,000	1,168	604	564	0	472	–	–	0.32	–	–	<5	–	0
Feb	1,780	5,500	1,372	668	704	0	460	3.8	0.003	0.10	0.055	<5	<5	3.5	C
Mar	1,850	6,000	1,490	700	790	0	430	4.0	0.004	–	0.052	<5	<5	–	–
Apr	–	–	–	–	–	0	–	–	–	<0.01	–	–	–	–	–
May	2,040	7,000	1,500	790	710	0	460	3.4	0.022	0.19	0.041	7	<5	–	27
Jun	1,920	7,000	–	–	–	0	–	3.8	–	–	0.062	–	–	–	–
PUMP INOPERATIVE DUE TO BRUSH FIRE JUL 1974—JUN 1975															
1975 Jul	1,870	5,500	–	–	–	0	–	–	0.011	–	–	–	–	–	–
Aug	1,880	5,000	1,400	722	678	0	458	4.1	0.008	0.11	–	–	–	–	>100
Sep	1,900	5,500	–	–	–	0	–	0.4	0.006	0.08	–	–	–	–	–

*Confluent colonies.

TABLE B-6. ANALYSIS OF SAMPLES TAKEN FROM WELL FP-6

Date		Chlorides mg/l	Conductivity μmhos/cm² at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1971	Jun	–	3,300	–	–	–	0	–	–	–	–	–	–	–	–	–
	Jul	–	3,200	–	–	–	0	–	–	–	–	–	–	–	–	–
	Aug	620	3,000	527	232	295	0	532	–	–	–	–	–	–	–	–
	Sep	600	3,000	500	236	264	0	532	–	–	–	–	–	–	–	–
	Oct	660	3,100	536	248	288	0	575	–	–	–	–	–	–	–	0
	Nov	660	3,100	532	236	296	0	548	–	–	–	–	–	–	–	–
	Dec	640	3,050	524	248	276	0	572	–	–	–	–	–	–	–	0
Mean		636	3,107	524	240	284	0	552	–	–	–	–	–	–	–	–
Std Dev		26	110	14	8	14	0	21	–	–	–	–	–	–	–	–
1972	Jan	620	2,800	524	252	272	0	588	–	–	–	–	–	–	–	0
	Feb	610	3,000	484	232	252	0	568	–	–	–	–	–	–	–	0
	Mar	590	3,000	496	224	272	0	552	–	–	–	–	–	–	–	–
	Apr	520	2,800	488	216	272	0	564	–	–	–	–	–	–	–	0
	May	580	2,900	484	216	268	0	560	–	–	–	–	–	–	–	–
	Jul	650	2,900	480	160	320	0	560	–	<1	0.34	0.069	–	–	27	–
	Aug	680	3,000	488	228	260	0	568	–	<1	0.33	0.090	–	–	–	–
	Sep	610	2,900	492	208	284	0	564	–	<1	0.38	0.085	–	–	39	–
	Oct	620	3,000	500	224	276	0	556	–	<1	0.38	0.083	–	–	7.6	–
	Nov	570	2,900	392	180	212	0	520	4.2	<1	0.87	0.035	–	–	–	–
	Dec	570	2,900	400	180	220	0	560	4.1	<1	0.44	0.066	–	–	6	–
Mean		602	2,918	475	211	264	0	560	4.2	–	0.49	0.070	–	–	20	–
Std Dev		43	75	41	27	29	0	16	0.1	–	0.21	0.020	–	–	16	–
1973	Jan	570	2,600	500	208	292	0	560	4.6	<1	0.42	0.083	–	–	–	–
	Feb	560	2,800	470	218	252	0	588	–	–	–	–	–	–	–	–
	Mar	600	3,000	508	232	276	0	532	3.5	–	0.63	0.090	–	–	11	0
	Apr	700	2,900	532	252	280	0	512	4.0	<0.010	0.09	0.085	–	–	–	0
	May	700	3,100	580	272	308	0	520	4.0	0.004	0.72	0.094	–	<5	14	–
	Jun	980	3,500	756	328	428	0	504	3.1	–	0.41	0.096	–	<5	7	>100

TABLE B-6 (CONTINUED).

Date	Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1973 Jul	1,260	4,000	964	448	516	0	488	4.1	<0.001	0.04	0.064	–	–	–	0
Aug	1,540	5,000	1,220	560	660	0	460	3.6	0.001	0.46	0.076	–	<5	0.1	2
Sep	1,590	5,500	–	–	–	0	–	3.5	–	0.44	0.102	–	–	–	0
Oct	1,660	5,500	1,652	620	1,032	0	472	4.1	–	0.20	0.090	–	<5	–	0
Nov	1,800	5,500	1,532	708	824	0	408	3.6	0.050	0.45	0.071	5	–	10	0
Dec	–	–	–	–	–	0	–	–	–	–	–	–	<15	–	–
Mean	1,087	3,945	871	385	487	0	505	3.8	–	0.39	0.090	–	–	–	–
Std Dev	492	1,199	450	186	270	0	51	0.4	–	0.22	0.010	–	–	–	–
1974 Jan	1,680	5,000	1,372	624	748	0	456	–	0.002	0.33	–	9	<5	–	0
Feb	1,960	6,000	1,620	748	872	0	436	3.6	<0.001	0.42	0.075	<5	<5	5.4	0
Mar	2,250	7,000	1,950	865	1,085	0	400	3.5	0.002	–	0.070	<5	<5	–	0
Apr	–	–	–	–	–	0	–	–	–	<0.01	–	–	–	–	–
May	2,600	8,500	2,130	980	1,150	0	440	3.0	0.001	–	0.066	<5	<5	–	0

PUMPING DISCONTINUED DUE TO THE HIGH CHLORIDE CONTENT

TABLE B-7. ANALYSIS OF SAMPLES TAKEN FROM WELL FP-8

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as CaCO$_3$	Ca mg/l as CaCO$_3$	Mg mg/l as CaCO$_3$	CO$_3$ mg/l as CaCO$_3$	HCO$_3$ mg/l as CaCO$_3$	NO$_3$-N mg/l	NO$_2$-N mg/l	NH$_3$-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1971	Jun	–	3,500	–	–	–	0	–	–	–	–	–	–	–	–	–
	Jul	–	3,200	–	–	–	0	–	–	–	–	–	–	–	–	–
	Aug	660	3,400	442	210	232	0	545	–	–	–	–	–	–	–	–
	Sep	600	3,000	412	204	208	0	572	–	–	–	–	–	–	–	–
	Oct	650	3,200	440	240	200	0	605	–	–	–	–	–	–	–	–
	Nov	630	3,050	460	224	236	0	608	–	–	–	–	–	–	–	–
	Dec	660	3,050	440	232	208	0	568	–	–	–	–	–	–	–	–
Mean		640	3,200	439	222	217	0	580	–	–	–	–	–	–	–	–
Std Dev		26	189	17	15	16	0	27	–	–	–	–	–	–	–	–
1972	Jan	660	3,000	428	220	208	0	596	–	–	–	–	–	–	–	–
	Feb	700	3,200	424	224	200	0	580	–	–	–	–	–	–	–	–
	May	660	3,200	432	220	212	0	580	–	–	–	–	–	–	–	–
	Jul	690	3,000	456	176	280	0	510	–	<1	0.49	0.069	–	–	20	–
	Aug	640	3,000	432	192	240	0	580	–	<1	0.44	0.081	–	–	–	–
	Sep	680	3,000	416	188	228	0	576	–	<1	0.46	0.070	–	–	15	–
	Oct	690	3,000	436	196	240	0	560	–	<1	–	0.059	–	–	–	–
	Nov	620	3,000	408	200	208	0	592	4.9	<1	0.50	0.071	–	–	6.6	–
	Dec	500	3,000	372	188	184	0	612	4.3	<1	0.25	0.047	–	–	6.0	0
Mean		649	3,044	423	200	222	0	576	4.6	–	0.43	0.070	–	–	12	–
Std Dev		62	88	23	17	28	0	29	0.4	–	0.10	0.010	–	–	7	–
1973	Jan	460	2,400	408	180	328	0	616	4.2	<1	0.46	0.060	–	–	24	0
	Feb	650	3,000	440	220	220	0	608	–	–	–	–	–	–	–	–
	Mar	650	3,000	472	252	220	0	588	–	–	0.49	0.051	–	–	–	0
	Apr	700	2,900	452	220	232	0	540	4.0	0.010	0.06	0.098	–	<5	12	4
	May	800	3,100	484	248	236	0	568	3.9	0.004	0.36	0.096	–	<5	–	21
	Jun	700	3,000	456	224	232	0	548	3.4	–	0.49	0.084	–	<5	7	0
	Jul	700	3,000	440	216	224	0	560	3.6	0.014	0.18	0.068	–	–	–	0
	Aug	670	3,000	448	216	232	0	548	5.7	–	0.47	0.076	–	<5	<0.1	4

TABLE B-7 (CONTINUED).

Date	Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total Hardness mg/l as CaCO$_3$	Ca mg/l as CaCO$_3$	Mg mg/l as CaCO$_3$	CO$_3$ mg/l as CaCO$_3$	HCO$_3$ mg/l as CaCO$_3$	NO$_3$-N mg/l	NO$_2$-N mg/l	NH$_3$-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1973 Sep	680	3,000	–	–	–	0	–	3.9	–	0.37	0.116	–	–	–	1
Oct	690	3,000	432	212	220	0	552	4.9	0.004	0.20	0.081	–	<5	–	0
Nov	670	2,800	480	220	260	0	540	4.4	–	0.15	0.076	<5	<5	–	0
WELL NOT OPERATING															
Mean	670	2,927	451	221	240	0	567	4.2	–	0.32	0.080	–	–	14	–
Std Dev	81	190	23	19	33	0	28	0.7	–	0.16	0.020	–	–	9	–
1974 Jan	700	3,000	492	224	268	0	536	–	0.002	0.10	–	<5	<5	–	0
Feb	680	3,000	488	216	272	0	540	4.1	<0.001	0.08	0.092	<5	<5	3.5	0
Mar	680	3,000	452	232	220	0	548	4.4	0.004	–	0.070	<5	<5	–	0
Apr	–	–	–	–	–	0	–	–	–	0.02	–	–	–	–	–
May	690	3,000	440	212	228	0	548	3.9	0.014	0.22	0.060	<5	<5	–	4
Jun	700	3,000	408	204	204	0	544	4.2	0.005	0.17	0.073	7	<5	–	0
Jul	680	2,800	416	212	204	0	536	4.3	0.002	0.34	0.101	<5	<5	16	2
Aug	680	2,600	416	204	212	0	536	4.2	0.005	0.30	0.063	8	–	–	0
Sep	720	2,400	460	216	244	0	540	–	0.003	<0.01	0.076	<5	–	–	49
Oct	720	2,800	444	204	240	0	532	–	0.004	–	–	<5	–	–	1
Nov	–	–	–	–	–	0	–	–	0.003	0.15	–	<5	–	–	–
PUMP TURNED OFF NOV 1974–JAN 1975															
1975 Jan	730	2,800	–	–	–	0	–	4.3	0.007	–	0.077	<5	–	–	–
Feb	750	2,800	464	228	236	0	544	4.8	0.004	0.27	0.066	7	–	–	0
Mar	750	2,800	–	–	–	0	–	4.2	<0.001	0.16	0.059	<5	–	–	–
May	680	2,800	–	–	–	0	–	5.8	0.002	–	0.070	–	–	–	–
Jun	750	3,000	458	217	241	0	540	–	0.008	0.10	0.083	–	–	–	0
Jul	692	2,800	–	–	–	0	–	4.4	0.006	0.16	0.082	–	–	–	–
Aug	700	2,800	441	217	224	0	542	4.1	0.005	0.11	0.064	–	–	–	0
Sep	700	3,000	–	–	–	0	–	3.6	0.006	0.23	0.062	–	–	–	–

TABLE B-8. ANALYSIS OF SAMPLES TAKEN FROM WELL GG-1

Date	Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1971 Sep	200	1,675	368	316	52	0	636	–	–	–	–	–	–	–	–
Oct	200	1,800	292	204	88	0	675	–	–	–	–	–	–	–	–
Nov	190	1,630	300	140	160	0	660	–	–	–	–	–	–	–	44
Dec	200	1,800	306	116	190	0	640	–	–	–	–	–	–	–	225
Mean	196	1,726	317	194	123	0	653	–	–	–	–	–	–	–	–
Std Dev	5	87	35	89	64	0	18	–	–	–	–	–	–	–	–
1972 Jan	210	1,650	296	140	156	0	660	–	–	–	–	–	–	–	17
Feb	210	1,770	300	120	180	0	636	–	–	–	–	–	–	–	–
Mar	210	1,750	304	128	176	0	640	–	–	–	–	–	–	–	45
Apr	230	1,650	312	116	196	0	652	–	–	–	–	–	–	–	93
May	185	1,800	296	120	176	0	644	–	–	–	–	–	–	–	–
Jul	210	1,800	320	104	216	0	642	–	<1	0.42	0.056	–	–	25	–
Aug	230	1,700	297	108	189	0	648	–	<1	0.41	0.065	–	–	–	–
Sep	240	1,700	320	128	292	0	640	–	<1	0.40	0.058	–	–	44	–
Oct	240	1,700	304	128	176	0	624	–	<1	0.46	0.059	–	–	5	–
Nov	210	1,700	320	128	292	0	640	–	<1	0.49	0.057	–	–	–	–
Dec	210	1,500	360	152	208	0	632	–	<1	0.46	0.051	–	–	14.3	–
Mean	217	1,703	312	125	205	0	643	–	–	0.44	0.060	–	–	22	–
Std Dev	17	84	19	14	46	0	8	–	–	0.04	0.001	–	–	17	–
1973 Jan	220	1,700	320	144	176	0	640	–	<1	0.44	0.060	–	–	–	–
Feb	210	1,600	352	128	224	0	664	–	–	–	–	–	–	7	–
Mar	–	–	–	–	–	0	–	2.9	–	0.76	0.073	–	–	12	5
Apr	260	1,700	352	156	196	0	572	2.5	0.010	0.12	0.085	–	–	–	10
May	280	1,700	336	140	196	0	592	2.3	0.004	0.41	0.096	–	<5	17	40
Jun	260	1,650	340	156	184	0	600	2.6	–	0.56	0.084	–	<5	–	55
WELL DISMANTLED FOR DISINFECTION															
Aug	–	–	–	–	–	0	–	–	–	0.49	–	–	–	–	8
Sep	–	–	–	–	–	0	–	–	–	0.35	–	–	–	–	0

TABLE B-8 (CONTINUED).

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1973	Oct	380	2,000	456	196	260	0	556	–	–	0.09	–	–	<5	–	28
	Nov	370	2,000	440	192	248	0	554	–	0.001	0.30	–	<5	<5	12	38
	Dec	400	2,200	424	160	264	0	536	1.9	0.001	0.22	0.084	<5	–	7	10
Mean		298	1,819	378	159	219	0	589	2.4	0.370	0.08	–	–	–	11	–
Std Dev		75	217	53	24	35	0	44	0.4	0.200	0.01	–	–	–	4	–
1974	Jan	490	2,400	412	160	252	0	542	2.5	0.100	0.01	0.066	9	<5	–	54
	Feb	520	2,400	404	140	264	0	500	1.6	0.001	0.01	–	<5	<5	3.5	400
	Mar	520	2,600	444	176	268	0	548	1.2	0.002	–	0.052	23	<5	–	10
	Apr	–	–	–	–	–	0	–	–	–	0.12	–	–	–	–	–
	May	540	2,800	424	164	260	0	540	1.2	0.002	0.31	0.046	<5	<5	–	0
	Jun	530	2,600	416	172	244	0	520	0.9	0.001	0.23	0.040	<5	6	–	20
	Jul	550	2,200	400	160	240	0	536	1.5	0.001	0.29	0.088	<5	<5	12	0
	Aug	590	2,400	416	160	256	0	528	0.8	0.002	0.24	0.055	<5	–	–	[illegible]
	Sep	600	2,400	–	–	–	0	–	–	–	0.30	0.027	8	–	–	–
	Oct	620	2,400	428	164	264	0	526	1.0	0.002	0.32	0.048	<5	–	–	128
	Nov	–	–	–	–	–	0	–	–	0.003	–	–	5	–	–	–
	Dec	260	1,600	–	–	–	0	–	1.0	–	–	0.086	–	–	–	–
1975	Jan	280	1,600	464	182	282	0	604	1.9	0.002	0.27	0.090	11	–	–	192
	Feb	260	1,600	452	192	260	0	600	1.8	0.002	0.38	0.088	<5	<5	–	8
	Mar	270	1,600	–	–	–	0	–	1.3	–	0.17	0.079	<5	–	–	–
	Apr	270	1,700	438	166	272	0	592	–	–	–	–	–	–	–	131
	May	270	1,800	450	182	268	0	584	1.3	0.002	0.41	0.076	–	–	–	305
	Jun	270	1,700	446	179	265	0	572	–	0.003	0.16	0.074	–	–	–	–
	Jul	264	1,700	–	–	–	0	–	1.3	0.002	0.07	0.088	–	–	–	–
	Aug	300	1,800	418	175	243	0	588	1.3	0.001	–	0.075	–	–	–	0
	Sep	300	1,700	–	–	–	0	–	1.4	0.002	0.85	0.067	–	–	–	–

TABLE B-9. ANALYSIS OF SAMPLES TAKEN FROM WELL GG-8

Date		Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1971	Jun	–	2,650	–	–	–	0	–	–	–	–	–	–	–	–	–
	Jul	–	2,500	–	–	–	0	–	–	–	–	–	–	–	–	–
	Aug	445	2,650	273	111	162	0	571	–	–	–	–	–	–	–	–
	Sep	410	2,400	284	128	154	0	564	–	–	–	–	–	–	–	–
	Oct	–	–	–	–	–	0	–	–	–	–	–	–	–	–	1
	Nov	420	2,400	288	124	164	0	592	–	–	–	–	–	–	–	–
	Dec	430	2,500	272	112	160	0	592	–	–	–	–	–	–	–	26
Mean		426	2,500	279	119	160	0	580	–	–	–	–	–	–	–	–
Std Dev		14	122	8	9	4	0	14	–	–	–	–	–	–	–	–
1972	Jan	440	2,450	284	124	160	0	608	–	–	–	–	–	–	–	0
	Feb	400	2,250	272	132	140	0	580	–	–	–	–	–	–	–	–
	Mar	450	2,500	284	88	196	0	564	–	–	–	–	–	–	–	0
	Apr	–	–	–	–	–	0	–	–	–	–	–	–	–	–	3
	May	450	2,600	272	120	152	0	584	–	–	–	–	–	–	–	–
	Jul	445	2,400	272	98	174	0	590	–	<1	0.50	0.066	–	–	2.3	–
	Aug	460	2,400	264	104	160	0	600	–	<1	0.43	0.092	–	–	–	–
	Sep	480	2,400	280	108	172	0	600	–	<1	0.48	0.070	–	–	4.1	–
	Oct	500	2,200	292	128	164	0	568	–	<1	0.44	0.075	–	–	–	–
	Nov	450	2,400	260	108	152	0	592	–	–	–	–	–	–	4.5	–
	Dec	450	2,200	292	120	172	0	612	–	–	–	0.068	–	–	–	–
Mean		453	2,380	277	113	164	0	580	–	–	0.46	0.070	–	–	4	–
Std Dev		26	130	11	14	16	0	16	–	–	0.03	0.010	–	–	1	–
1973	Jan	450	2,200	292	108	184	0	612	6.3	<1	0.64	0.070	–	–	5.5	–
	Feb	–	2,400	–	–	–	0	–	–	–	–	–	–	–	–	–
	Mar	450	2,600	264	112	152	0	580	4.2	–	0.78	0.070	–	–	–	0
	Apr	470	2,400	260	116	144	0	572	5.2	<0.01	0.09	0.082	–	–	–	0
	May	500	2,800	284	132	152	0	580	5.4	0.004	0.64	0.090	–	<5	14	0
	Jun	500	2,500	228	132	96	0	588	4.6	–	0.58	0.084	–	<5	–	5

TABLE B-9 (CONTINUED).

Date	Chlorides mg/l	Conductivity μmhos/cm² at 25° C	Total Hardness mg/l as CaCO₃	Ca mg/l as CaCO₃	Mg mg/l as CaCO₃	CO₃ mg/l as CaCO₃	HCO₃ mg/l as CaCO₃	NO₃-N mg/l	NO₂-N mg/l	NH₃-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1973 Jul	540	2,600	296	124	172	0	580	5.6	0.001	0.15	0.060	–	<5	2	0
Aug	530	2,700	296	148	148	0	572	2.0	<0.001	0.39	0.068	–	<5	–	1
Sep	530	2,800	–	–	–	0	–	4.9	–	0.39	0.114	–	<5	–	0
Oct	530	2,800	292	140	152	0	588	6.1	–	0.02	0.087	–	<5	–	1
Nov	530	2,600	284	128	156	0	580	5.8	0.001	0.39	0.060	<5	–	11	2
Dec	550	2,800	308	104	204	0	576	5.7	<0.001	0.24	0.076	<5	<5	9	0
Mean	507	2,600	280	132	156	0	583	5.2	–	0.39	0.080	–	–	8	–
Std Dev	36	195	24	22	28	0	12	1.0	–	0.25	0.020	–	–	5	–
1974 Jan	550	2,700	292	156	136	0	580	5.3	0.001	<0.01	0.081	6	<5	–	1
Feb	550	2,700	264	92	172	0	560	6.3	0.001	0.04	0.073	<5	<5	4	0
Mar	560	3,000	304	136	168	0	600	1.3	0.001	–	0.075	12	<5	–	0
Apr	–	–	–	–	–	0	–	–	–	0.02	–	–	–	–	–
May	550	3,000	288	128	160	0	596	4.7	0.001	0.20	0.068	<5	<5	5.25	0
Jun	570	3,000	280	132	148	0	612	5.7	<0.001	0.37	0.065	7	5	–	1
Jul	550	2,600	284	124	160	0	588	3.3	0.001	0.38	0.094	<5	<5	6	10
Aug	520	2,400	–	–	–	0	–	5.5	<0.001	0.47	0.066	<5	–	–	–
Sep	560	2,200	320	128	192	0	580	–	0.002	0.21	–	<5	–	–	0
Oct	580	2,500	308	128	180	0	582	5.0	0.002	0.24	0.093	<5	–	–	0
Nov	–	–	–	–	–	0	–	–	0.001	–	–	<5	–	–	–
Dec	500	2,200	–	–	–	0	–	4.7	–	–	0.072	–	–	–	–
1975 Jan	530	2,400	300	136	164	0	584	4.8	0.002	0.11	0.077	5	<5	–	0
Feb	540	2,400	312	144	168	0	588	5.7	0.005	0.23	0.070	<5	–	–	–
Mar	540	2,400	–	–	–	0	–	5.7	–	0.13	0.065	<5	–	–	–
Apr	530	2,400	295	121	174	0	584	5.6	–	–	–	–	–	–	0
May	530	2,400	–	–	–	0	–	5.7	0.004	–	0.067	–	–	–	–
Jun	540	2,600	307	124	183	0	600	–	–	0.12	0.077	–	–	–	0
Jul	528	2,400	–	–	–	0	–	5.1	0.001	0.11	0.064	–	–	–	–
Aug	560	2,600	293	126	167	0	580	5.4	0.002	–	–	–	–	–	0
Sep	–	–	–	–	–	0	–	5.4	–	–	0.028	–	–	–	–

TABLE B-10. ANALYSIS OF SAMPLES TAKEN FROM WELL GG-9

Date	Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as CaCO$_3$	Ca mg/l as CaCO$_3$	Mg mg/l as CaCO$_3$	CO$_3$ mg/l as CaCO$_3$	HCO$_3$ mg/l as CaCO$_3$	NO$_3$-N mg/l	NO$_2$-N mg/l	NH$_3$-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1971 Jun	–	1,625	–	–	–	0	–	–	–	–	–	–	–	–	–
Jul	–	1,600	–	–		0	–	–	–	–	–	–	–	–	–
Aug	200	1,600	378	152	226	0	483	–	–	–	–	–	–	–	–
Sep	210	1,550	372	170	202	0	476	–	–	–	–	–	–	–	–
Oct	220	1,675	372	172	200	0	520	–	–	–	–	–	–	–	21
Nov	220	1,650	380	172	208	0	532	–	–	–	–	–	–	–	–
Dec	250	1,700	392	172	220	0	556	–	–	–	–	–	–	–	–
Mean	220	1,628	379	168	211	0	513	–	–	–	–	–	–	–	–
Std Dev	19	51	8	9	11	0	34	–	–	–	–	–	–	–	–
1972 Jan	240	1,600	380	172	208	0	528	–	–	–	–	–	–	–	2
Feb	260	1,600	376	172	104	0	504	–	–	–	–	–	–	–	–
Mar	240	1,600	–	–	–	0	–	–	–	–	–	–	–	–	0
Apr	–	–	–	–	–	0	–	–	–	–	–	–	–	–	0
May	–	–	–	–	–	0	–	–	–	–	–	–	–	–	49
Jun	200	1,600	380	168	212	0	504	–	–	–	–	–	–	–	–
Jul	250	1,600	308	168	140	0	508	–	<1	0.27	0.076	–	–	17	12
Aug	230	1,500	380	140	240	0	508	–	<1	0.38	0.081	–	–	–	52
Sep	240	1,500	388	164	224	0	504	–	<1	0.40	0.080	–	–	12	>100
Oct	250	1,500	400	168	232	0	492	–	<1	0.48	0.083	–	–	4.0	25
Nov	220	1,500	400	168	232	0	508	2.6	<1	0.62	0.083	–	–	5.2	–
Dec	230	1,500	384	168	216	0	500	2.9	<1	–	0.085	–	–	4.5	–
Mean	236	1,550	377	165	201	0	506	2.8	–	0.43	0.080	–	–	9	–
Std Dev	17	53	27	10	47	0	10	0.2	–	0.13	–	–	–	6	–
PUMP BEING REPAIRED															
1973 Apr	260	1,500	–	–	–	0	–	1.7	–	–	–	–	<5	14	–
May	260	1,500	600	200	400	0	468	1.6	0.004	0.43	0.094	–	<5	–	–

TABLE B-10 (CONTINUED).

Date	Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1973 Jun	-	-	-	-	-	0	-	4.8	-	0.59	0.092	-	-	8	-
Jul	300	1,500	420	196	224	0	480	5.7	0.002	0.14	0.100	-	-	-	-
Aug	250	1,600	440	196	244	0	460	1.1	<0.001	0.42	0.082	-	<5	1	-
PUMP NOT RUNNING															
Oct	330	1,900	540	232	308	0	-	-	-	0.19	-	-	<5	-	-
Nov	270	1,600	500	216	284	0	460	0.4	0.002	0.06	0.056	<5	<5	10	7
Dec	260	1,600	456	192	264	0	456	1.2	<0.001	0.07	0.084	<5	<5	4	4
Mean	276	1,600	493	205	287	0	465	2.4	-	0.27	0.080	-	-	7	-
Std Dev	29	141	68	16	63	0	10	2.0	-	0.21	0.020	-	-	5	-

DENIED ACCESS TO PUMP BY OWNER - SAMPLING DISCONTINUED

TABLE B-11. ANALYSIS OF SAMPLES TAKEN FROM WELL MB-1

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1971	Jul	–	7,000	–	–	–	0	–	–	–	–	–	–	–	–	–
	Aug	1,775	6,800	362	216	146	0	425	–	–	–	–	–	–	–	–
	Sep	1,810	6,800	453	244	209	0	444	–	–	–	–	–	–	–	–
	Nov	1,810	6,000	–	244	–	0	–	–	–	–	–	–	–	–	–
	Dec	1,800	6,500	456	232	224	0	452	–	–	–	–	–	–	–	0
Mean		1,799	6,620	424	234	193	0	440	–	–	–	–	–	–	–	–
Std Dev		17	390	53	13	41	0	14	–	–	–	–	–	–	–	–
1972	Jan	1,790	6,000	440	236	204	0	468	–	–	–	–	–	–	–	>100
	Feb	1,820	6,100	444	224	220	0	472	–	–	–	–	–	–	–	–
	Mar	1,860	6,000	388	168	220	0	392	–	–	–	–	–	–	–	2
	Apr	1,650	6,100	468	248	220	0	464	–	–	–	–	–	–	–	20
	May	1,670	6,500	456	248	208	0	460	–	–	–	–	–	–	–	–
	Jul	1,830	6,000	460	204	256	0	468	–	<1	–	0.015	–	–	7	–
	Aug	1,860	6,000	460	164	296	0	464	–	<1	0.39	0.047	–	–	–	–
	Sep	1,890	6,000	464	220	244	0	472	–	<1	0.38	0.042	–	–	15	–
	Oct	1,900	6,000	448	240	208	0	456	–	<1	0.43	0.015	–	–	7	–
	Nov	1,840	6,000	448	224	224	0	460	6.3	<1	0.33	0.023	–	–	–	–
	Dec	1,700	6,000	436	216	220	0	480	5.3	<1	0.30	0.012	–	–	–	–
Mean		1,800	6,064	447	218	229	0	460	5.8	–	0.37	0.026	–	–	10	–
Std Dev		88	151	22	29	27	0	23	0.7	–	0.05	0.015	–	–	5	–
1973	Jan	1,680	6,000	508	248	260	0	484	5.8	1	0.35	0.015	–	–	–	–
	Feb	1,680	6,000	436	280	156	0	188	–	–	–	–	–	–	6.5	2
	Mar	1,670	6,000	436	232	204	0	452	4.2	–	0.73	0.016	–	–	15	69
	Apr	1,870	6,500	440	240	200	0	440	4.3	<0.01	0.20	0.010	–	–	–	–
	May	1,800	6,000	–	–	–	0	–	5.0	–	0.34	0.021	–	<5	–	9
	Jun	1,860	6,000	472	252	220	0	456	4.5	–	0.35	0.032	–	<5	12	8

TABLE B-11 (CONTINUED).

Date	Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
Jul	1,880	6,000	492	256	236	0	464	5.7	0.027	0.05	0.012	–	<5	–	0
Aug	1,810	6,000	464	240	224	0	448	5.4	0.001	0.48	0.016	–	<5	4	>100
Sep	1,830	7,000	464	240	224	0	–	5.1	–	0.34	0.072	–	<5	–	2
Oct	1,810	6,000	500	252	248	0	452	5.6	–	0.17	0.030	–	<5	–	C*
Nov	1,820	6,000	444	232	212	0	424	5.1	<0.001	0.21	0.024	5	<5	12	2
Dec	1,800	6,000	460	240	220	0	436	5.6	–	0.02	0.017	–	<5	–	0
Mean	1,793	6,125	465	247	219	0	424	5.1	–	0.29	0.024	–	–	10	–
Std Dev	75	311	26	14	27	0	85	0.6	–	0.20	0.017	–	–	5	–
1974 Jan	1,810	6,000	480	232	248	0	444	4.4	0.01	<0.01	0.010	<5	12	–	4
Feb	1,810	6,000	–	–	–	0	–	5.1	–	–	0.026	–	–	–	–

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*Confluent colonies.

TABLE B-12. ANALYSIS OF SAMPLES TAKEN FROM WELL MB-2

Date	Chlorides mg/l	Conductivity µmhos/cm² at 25° C	Total Hardness mg/l as CaCO₃	Ca mg/l as CaCO₃	Mg mg/l as CaCO₃	CO₃ mg/l as CaCO₃	HCO₃ mg/l as CaCO₃	NO₃-N mg/l	NO₂-N mg/l	NH₃-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1971 Aug	270	1,950	248	104	144	0	564	–	–	–	–	–	–	–	–
Sep	280	1,840	252	104	148	0	552	–	–	–	–	–	–	–	–
Oct	270	1,900	256	104	152	0	600	–	–	–	–	–	–	–	–
Nov	270	1,900	276	112	164	0	600	–	–	–	–	–	–	–	–
Dec	290	1,950	248	104	144	0	584	–	–	–	–	–	–	–	0
Mean	276	1,908	256	106	150	0	580	–	–	–	–	–	–	–	–
Std Dev	9	46	12	4	8	0	22	–	–	–	–	–	–	–	–
1972 Jan	280	1,750	268	112	156	0	564	–	–	–	–	–	–	–	0
Feb	270	1,900	252	112	140	0	592	–	–	–	–	–	–	–	–
Mar	270	1,900	236	100	136	0	576	–	–	–	–	–	–	–	–
Apr	–	–	–	–	–	0	–	–	–	–	–	–	–	–	0
May	250	1,900	248	100	148	0	584	–	–	–	–	–	–	–	–
Jul	255	1,800	250	106	144	0	576	–	–	–	–	–	–	–	–
Aug	290	1,800	264	104	160	0	456	–	<1	0.41	0.042	–	–	20	–
Sep	330	1,800	252	104	148	0	580	–	<1	0.49	0.042	–	–	16	–
Oct	280	1,800	264	112	152	0	456	–	<1	0.50	0.041	–	–	5	–
Nov	260	1,800	256	100	156	0	580	–	<1	0.40	0.047	–	–	6.4	–
Dec	–	–	–	–	–	0	–	5.2	<1	0.40	0.043	–	–	5.0	–
Mean	276	1,828	255	106	149	0	552	–	–	0.44	0.043	–	–	10	–
Std Dev	24	57	10	5	8	0	55	–	–	0.05	0.002	–	–	7	–
1973 Jan	–	–	–	–	–	0	–	5.7	<1	0.46	0.045	–	–	–	–
Feb	240	1,800	252	107	145	0	616	–	–	–	–	–	–	15	–
Mar	280	1,800	248	120	128	0	572	3.9	–	0.54	0.055	–	–	–	1
Apr	260	1,710	264	112	152	0	540	2.6	<0.01	0.05	0.046	–	–	–	0
May	280	1,750	268	112	156	0	548	4.5	0.004	0.55	0.050	–	<5	18	0
Jun	300	1,700	260	116	144	0	560	4.2	–	0.57	0.060	–	<5	–	3
Jul	300	1,500	276	124	152	0	572	5.1	0.005	0.16	0.032	–	<5	–	0
Aug	270	1,800	264	112	152	0	540	–	<0.001	–	–	–	<5	< 0.1	5

TABLE B-12 (CONTINUED).

Date		Chlorides mg/l	Conductivity µmhos/cm² at 25° C	Total Hardness mg/l as CaCO₃	Ca mg/l as CaCO₃	Mg mg/l as CaCO₃	CO₃ mg/l as CaCO₃	HCO₃ mg/l as CaCO₃	NO₃-N mg/l	NO₂-N mg/l	NH₃-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1973	Sep	280	1,800	–	–	–	0	–	4.0	–	0.06	0.062	–	<5	–	0
	Oct	290	1,900	280	124	156	0	556	5.1	–	0.26	0.076	–	<5	–	0
	Nov	280	1,700	268	148	120	0	540	4.1	<0.001	0.09	0.045	<5	<5	10	0
	Dec	290	1,800	280	128	152	0	–	4.1	<0.001	0.05	0.058	<5	<5	4	0
Mean		279	1,751	266	120	146	0	560	4.3	–	0.28	0.053	–	–	–	–
Std Dev		18	102	11	12	12	0	25	0.9	–	0.23	0.012	–	–	–	–
1974	Jan	290	1,800	312	128	184	0	548	4.4	–	<0.01	0.037	–	<5	–	0
	Feb	290	1,800	288	112	176	0	540	4.2	<0.001	–	0.050	<5	<15	3	0
	Mar	290	1,900	284	120	164	0	572	–	0.001	–	–	<5	<5	–	0
	Apr	–	–	–	–	–	0	–	–	–	0.08	–	–	–	–	–
	May	290	1,900	272	112	160	0	560	–	<0.001	0.20	–	<5	<5	4.8	0
	Jun	290	1,800	260	–	–	0	–	4.7	<0.001	0.24	0.051	6	<5	–	1
	Jul	280	1,700	256	112	144	0	–	4.7	<0.001	0.36	0.088	<5	<5	6	2
	Aug	290	1,600	248	96	152	0	548	4.6	0.002	0.42	0.043	<5	–	–	0
	Sep	290	1,500	288	108	180	0	540	–	0.001	0.18	0.073	<5	–	–	0
	Oct	300	1,600	280	92	188	0	546	3.8	0.001	0.29	0.070	<5	–	–	–
	Nov	–	–	–	–	–	0	–	3.4	0.002	–	–	10	–	–	–
	Dec	300	1,600	–	–	–	0	–	–	–	–	0.058	–	–	–	–
1975	Jan	300	1,700	288	112	176	0	572	4.2	–	0.29	0.056	–	<5	–	0
	Feb	310	1,700	284	120	164	0	564	4.4	–	0.44	0.055	–	–	–	6
	Mar	–	–	–	–	–	0	–	–	–	0.16	–	–	–	–	–
	Apr	320	1,800	295	121	174	0	552	–	–	–	–	–	–	–	0
	May	340	1,800	295	132	163	0	544	–	0.003	0.18	–	–	–	–	–
	Jun	320	1,800	272	101	171	0	548	–	0.003	0.14	0.052	–	–	–	0
	Jul	345	1,800	–	–	–	0	–	4.4	0.002	0.15	0.058	–	–	–	–
	Aug	360	1,800	304	129	175	0	550	4.3	0.002	0.18	0.051	–	–	–	0
	Sep	340	1,900	–	–	–	0	–	4.0	0.008	0.06	0.052	–	–	–	–

TABLE B-13. ANALYSIS OF SAMPLES TAKEN FROM WELL NB-3

Date	Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1975 Feb	290	1,650	280	108	172	0	568	–	0.004	–	–	9	–	–	8
Mar	320	1,700	–	–	–	0	–	2.9	–	0.19	0.042	<5	–	–	–
Apr	300	1,700	279	117	162	0	552	–	–	–	–	–	–	–	0
May	320	1,700	287	116	171	0	–	3.8	0.004	0.46	0.042	–	–	–	–
Jun	330	1,800	–	–	–	0	–	–	0.002	0.46	0.046	–	–	–	–
Jul	325	1,800	–	–	–	0	–	2.8	0.002	0.13	0.050	–	–	–	–
Aug	335	1,900	–	–	–	0	–	–	0.002	–	0.039	–	–	–	–

TABLE B-14. ANALYSIS OF SAMPLES TAKEN FROM WELL NB-4

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1975	Feb	290	1,600	296	124	172	0	560	–	0.005	–	–	9	–	–	0
	Mar	310	1,700	–	–	–	0	–	4.1	–	0.14	0.039	<5	–	–	–
	Apr	310	1,700	322	109	213	0	540	–	–	–	–	–	–	–	1
	May	330	1,700	330	136	194	0	540	5.3	0.001	0.35	0.036	–	–	–	–
	Jun	330	1,800	330	136	194	0	540	–	0.003	–	0.063	–	–	–	–
	Jul	–	–	–	–	–	0	–	–	–	0.08	–	–	–	–	–

TABLE B-15. ANALYSIS OF SAMPLES TAKEN FROM WELL NB-5

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1975	Feb	350	1,800	372	172	200	0	528	–	0.001	–	–	7	--	–	0
	Mar	380	1,800	–	–	–	0	–	7.3	–	0.17	0.650	–	--	–	–
	Jul	426	2,220	–	–	–	0	–	–	0.002	0.08	–	–	--	–	–
	Aug	440	2,200	384	145	239	0	533	7.8	0.003	–	0.067	–	--	–	0

TABLE B-16. ANALYSIS OF SAMPLES TAKEN FROM WELL P-1

Date	Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1971 Aug	1,240	5,100	372	228	144	0	648	–	–	–	–	–	–	–	–
Sep	1,130	5,000	332	200	132	0	632	–	–	–	–	–	–	–	–
Oct	1,050	4,550	260	164	96	0	700	–	–	–	–	–	–	–	–
Nov	1,160	5,000	368	220	148	0	668	–	–	–	–	–	–	–	–
Dec	1,140	5,000	320	180	140	0	652	–	–	–	–	–	–	–	–
Mean	1,144	4,930	330	198	132	0	660	–	–	–	–	–	–	–	–
Std Dev	68	215	45	27	21	0	26	–	–	–	–	–	–	–	–
1972 Jan	1,300	5,100	420	248	212	0	692	–	–	–	–	–	–	–	3
Feb	1,300	5,200	396	232	164	0	672	–	–	–	–	–	–	–	–
Mar	1,250	5,000	–	–	–	0	678	–	–	–	–	–	–	–	–
Jul	1,340	5,000	424	240	184	0	680	–	–	–	–	–	–	–	–
Aug	1,290	5,000	380	180	200	0	668	–	–	–	–	–	–	–	–
Sep	1,250	5,000	384	188	196	0	660	–	–	–	–	–	–	–	–
Oct	1,300	5,000	440	200	240	0	664	–	–	–	–	–	–	–	–
Nov	1,200	5,000	380	180	200	0	654	–	–	–	–	–	–	–	–
Dec	1,300	5,000	400	180	220	0	–	–	–	–	–	–	–	–	–
Mean	1,281	5,033	403	206	202	0	671	–	–	–	–	–	–	–	–
Std Dev	41	71	23	29	23	0	12	–	–	–	–	–	–	–	–
1973 Jan	1,280	6,000	452	224	228	0	672	–	–	–	–	–	–	–	–
Feb	1,350	5,500	478	288	290	0	741	–	–	–	–	–	–	–	–
Mar	1,300	5,500	432	268	164	0	652	–	–	0.55	0.029	–	–	–	0
Apr	1,410	5,000	436	268	168	0	616	1.7	<0.010	0.04	0.028	–	–	–	0
May	1,400	5,000	436	256	180	0	640	0.8	0.004	0.84	0.060	–	<5	39	0
Jun	1,400	5,000	440	260	180	0	632	3.1	–	0.42	0.046	–	<5	–	0
Jul	1,400	5,000	468	280	188	0	652	1.8	0.002	0.18	0.012	–	–	14	0
Aug	1,440	5,500	488	292	196	0	636	2.2	<0.001	0.42	0.026	–	<5	3	0

TABLE B-16 (CONTINUED).

Date		Chlorides mg/l	Conductivity µmhos/cm² at 25° C	Total Hardness mg/l as CaCO₃	Ca mg/l as CaCO₃	Mg mg/l as CaCO₃	CO₃ mg/l as CaCO₃	HCO₃ mg/l as CaCO₃	NO₃-N mg/l	NO₂-N mg/l	NH₃-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1973	Sep	1,460	5,500	–	–	–	0	–	1.4	–	0.26	0.047	–	–	–	1
	Oct	1,460	5,500	520	196	324	0	644	2.4	–	0.17	0.032	–	<5	–	0
	Nov	1,450	5,500	460	264	196	0	604	3.3	<0.001	0.32	0.022	6	<5	27	0
	Dec	1,320	5,500	424	248	176	0	716	2.1	<0.001	0.08	0.080	5	<5	3	0
Mean		1,383	5,375	458	259	208	0	655	2.1	–	0.33	0.040	6	–	17	–
Std Dev		63	311	29	28	52	0	41	0.8	–	0.24	0.020	1	–	16	–
1974	Jan	1,520	6,000	544	304	240	0	652	2.0	<0.001	0.06	0.006	8	<5	–	0
	Feb	1,490	5,500	432	220	212	0	576	2.3	<0.001	0.12	0.034	<5	<5	4.5	11
	Mar	1,420	6,000	488	288	200	0	644	2.4	<0.001	–	0.023	<5	<5	–	0
	Apr	–	–	–	–	–	0	–	–	–	0.03	–	–	–	–	–
	May	1,360	6,000	404	232	172	0	652	2.8	<0.001	0.34	0.019	<5	<5	–	75
	Jun	1,400	5,500	352	180	172	0	580	2.9	<0.001	0.22	0.027	6	5	–	C*
	Jul	1,410	5,000	444	264	180	0	632	2.8	0.002	0.40	0.056	–	<5	–	0
	Aug	1,260	4,000	368	220	148	0	628	2.9	0.002	0.59	0.250	6	–	–	0
	Sep	1,420	4,500	452	256	196	0	632	0.9	0.001	<0.01	0.052	9	–	–	0
	Oct	1,520	5,000	480	224	256	0	584	–	–	–	–	–	–	–	1
	Nov	–	–	–	–	–	0	–	–	0.051	–	–	11	–	–	–
	Dec	1,390	5,000	–	–	–	0	–	3.9	–	–	0.032	–	–	–	–
1975	Jan	1,350	5,000	400	212	188	0	–	5.8	0.002	0.19	0.035	17	<5	–	44
	Feb	1,320	4,500	376	232	144	0	632	5.5	0.004	0.29	0.032	7	–	–	11
	Mar	–	–	–	–	–	0	–	4.6	–	0.14	0.022	8	–	–	–
	Apr	1,310	4,500	384	214	170	0	628	–	–	–	–	–	–	–	0
	May	1,320	4,500	400	225	175	0	636	4.9	0.002	0.16	0.021	–	–	–	–
	Jun	1,340	5,000	396	225	171	0	632	–	0.003	0.15	0.036	–	–	–	0
	Jul	1,350	5,000	–	–	–	0	–	4.1	0.001	0.11	0.035	–	–	–	–
	Aug	1,500	5,000	411	186	225	0	525	4.9	0.001	0.11	0.024	–	–	–	–
	Sep	–	–	–	–	–	0	–	–	0.002	0.08	–	–	–	–	–

*Confluent colonies.

TABLE B-17. ANALYSIS OF SAMPLES TAKEN FROM WELL PW-1

Date	Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1972 Jul	210	1,500	388	180	208	0	500	–	–	–	–	–	–	–	–
1974 Jan	310	1,800	520	240	280	0	512	–	–	–	–	–	–	–	–
Feb	300	1,700	516	232	284	0	524	–	–	–	–	–	–	–	–
May	300	1,700	468	192	276	0	468	–	–	–	–	–	–	–	–
Jun	320	1,900	384	168	216	0	456	–	–	–	–	–	–	–	–
Jul	280	1,600	372	172	200	0	500	5.8	0.004	0.16	0.075	5	<5	12	–
Aug	270	1,500	368	164	204	0	500	2.8	0.029	0.11	0.030	<5	–	–	1
Sep	310	1,600	–	–	–	0	–	–	0.008	0.20	0.075	<5	–	–	–
Oct	460	1,800	268	120	148	0	276	5.4	0.002	0.33	0.065	<5	–	–	–
Nov	–	–	–	–	–	0	–	–	0.002	–	–	<5	–	–	–
Dec	270	1,400	–	–	–	0	–	4.4	–	–	0.069	–	–	–	–
1975 Jan	290	1,500	396	148	248	0	440	7.8	0.002	0.15	0.083	6	<5	–	0
Feb	300	1,500	416	184	232	0	464	5.5	0.002	0.29	0.066	5	–	–	0
Mar	310	1,600	–	–	–	0	–	4.7	–	0.18	0.048	<5	–	–	–
Apr	310	1,700	415	179	236	0	480	–	–	–	–	–	–	–	1
May	320	1,650	–	–	–	0	–	4.7	–	0.35	0.044	–	–	–	–
Jun	330	1,700	415	186	229	0	484	–	0.003	–	0.052	–	–	–	1
Jul	304	1,800	–	–	–	0	–	4.5	0.002	0.13	0.048	–	–	–	–
Aug	310	1,700	411	183	228	0	492	3.7	0.005	0.11	0.045	–	–	–	87
Sep	300	1,700	–	–	–	0	–	3.4	0.002	0.08	0.020	–	–	–	–

TABLE B-18. ANALYSIS OF SAMPLES TAKEN FROM WELL PW-2

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1972	Jul	230	1,700	216	40	176	0	620	–	–	–	–	–	–	–	–
1973	May	240	1,700	224	92	132	0	576	–	–	–	–	–	–	–	..
	Jun	340	1,500	224	104	120	0	530	–	–	–	–	–	–	–	2
	Jul	240	1,700	–	–	–	0	–	–	–	–	–	–	–	–	0
	Aug	230	1,700	216	104	112	0	564	–	<0.001	–	–	–	–	–	C*
	Sep	–	–	–	–	–	0	–	–	–	0.30	–	–	–	–	C
	Oct	220	1,700	236	104	132	0	568	–	–	–	–	–	<5	–	0
	Nov	230	1,600	244	116	128	0	564	–	<0.001	0.34	–	8	<5	15	C
Mean		250	1,650	229	104	125	0	560	–	–	0.32	–	–	–	–	–
Std Dev		45	84	11	8	9	0	18	–	–	0.03	–	–	–	–	–
1974	Jan	230	1,600	268	112	156	0	568	2.7	<0.001	0.07	–	7	<5	–	0
	Feb	240	1,600	220	72	148	0	500	–	0.002	0.04	0.043	<5	<5	4	C
	Mar	240	1,700	260	104	156	0	564	–	0.002	–	–	<5	<5	–	C
	Apr	–	–	–	–	–	0	–	–	–	<0.01	–	–	–	–	..
	May	250	1,700	224	100	124	0	560	–	0.002	0.26	–	<5	<5	–	10
	Jun	240	1,700	204	84	120	0	540	2.7	0.006	0.17	0.035	<5	<5	–	C
	Jul	240	1,600	224	100	124	0	552	2.6	0.007	0.37	0.078	<5	<5	–	0
	Aug	240	1,500	256	96	160	0	552	0.3	0.004	0.53	–	<5	–	–	0
	Sep	260	1,500	–	–	–	0	–	–	0.001	0.28	0.063	<5	–	–	–
	Oct	310	1,700	272	108	164	0	560	2.8	0.002	0.18	0.062	<5	–	–	0
	Nov	–	–	–	–	–	0	–	–	0.001	–	–	<5	–	–	–
	Dec	240	1,500	–	–	–	0	–	1.5	–	–	0.037	–	–	–	–
1975	Jan	270	1,600	248	84	164	0	584	2.6	0.004	0.12	0.037	<5	5	–	0
	Feb	260	1,550	240	100	140	0	584	2.8	0.003	0.26	0.032	7	–	–	0
	Mar	260	1,600	–	–	–	0	–	2.7	–	0.16	0.033	7	–	–	–
	Apr	250	1,600	245	93	152	0	568	–	0.001	–	–	–	–	–	0

TABLE B-18 (CONTINUED).

Date	Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1975 May	250	1,600	248	97	151	0	528	2.6	0.005	0.19	0.030	–	–	–	–
Jun	240	1,700	268	101	167	0	580	–	0.003	0.13	0.039	–	–	–	0
Jul	254	1,650	–	–	–	0	–	2.3	0.001	0.13	0.042	–	–	–	–
Aug	250	1,600	243	103	140	0	572	2.3	0.002	0.12	0.035	–	–	–	1
Sep	260	1,700	–	–	–	0	–	2.4	0.002	0.19	0.028	–	–	–	–

*Confluent colonies.

TABLE B-19. ANALYSIS OF SAMPLES TAKEN FROM WELL PW-4

Date	Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1972 Jul	230	–	216	40	176	0	620	–	–	–	–	–	–	–	–
Aug	290	1,850	368	140	228	0	564	–	–	–	–	–	–	–	–
Mean	260	–	292	90	202	0	592	–	–	–	–	–	–	–	–
Std Dev	42	–	107	71	37	0	40	–	–	–	–	–	–	–	–
1973 Jul	290	1,800	–	–	–	0	–	–	–	–	–	–	–	–	1
Aug	280	1,900	376	164	212	0	548	–	<0.001	0.45	–	–	–	–	0
Sep	–	–	–	–	–	0	–	–	–	–	–	–	–	–	0
Mean	285	1,850	–	–	–	0	–	–	–	–	–	–	–	–	–
Std Dev	7	71	–	–	–	0	–	–	–	–	–	–	–	–	–
1974 Jan	290	1,800	396	180	216	0	548	–	0.001	0.09	–	6	<5	–	0
Feb	290	1,800	388	176	212	0	556	2.5	<0.001	0.08	0.065	<5	<5	4	3
NOT IN OPERATION MAR 1974–MAY 1974															
Jun	300	1,900	348	160	188	0	552	–	–	0.19	–	–	–	–	0
Jul	280	1,700	356	168	188	0	540	2.7	0.001	0.28	0.078	<5	<5	6.8	3
Aug	300	1,600	372	156	216	0	536	2.4	0.002	0.26	0.059	<5	–	–	0
Sep	310	1,500	–	–	–	0	–	–	0.001	0.14	0.093	<5	–	–	–
Oct	320	1,650	448	180	268	0	536	2.8	0.002	0.11	0.090	<5	–	–	2
Nov	–	–	–	–	–	0	–	–	0.001	–	–	<5	–	–	–
Dec	240	1,500	–	–	–	0	–	2.0	–	–	0.058	–	–	–	–
1975 Jan	320	1,700	396	156	240	0	536	3.7	0.002	0.33	0.063	<5	<5	–	0
Feb	310	1,700	396	168	228	0	544	3.7	0.003	0.40	0.070	<5	–	–	2
Mar	330	1,700	–	–	–	0	–	3.6	–	0.09	0.045	<5	–	–	–
Apr	300	1,900	385	171	214	0	528	–	–	–	–	–	–	–	5
May	330	1,700	392	172	220	0	528	–	0.002	0.22	–	–	–	–	–
Jun	310	1,800	385	171	214	0	532	–	0.003	0.07	0.063	–	–	–	15

TABLE B-19 (CONTINUED).

Date	Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1975 Jul	304	1,700	–	–	–	0	–	–	0.002	0.16	0.050	–	–	–	–
Aug	300	1,700	380	171	209	0	534	–	0.001	0.06	0.058	–	–	–	0
Sep	310	1,700	–	–	–	0	–	–	0.002	0.08	0.040	–	–	–	–

TABLE B-20. ANALYSIS OF SAMPLES TAKEN FROM WELL PW-6*

Date		Chlorides mg/l	Conductivity μmhos/cm² at 25° C	Total Hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1974	Aug	350	1,500	468	172	296	0	424	0.3	0.068	1.11	0.220	5	–	–	–
	Sep	370	1,600	–	–	–	0	–	–	0.034	0.24	0.036	<5	–	–	–
	Oct	330	1,500	412	180	232	0	436	0.7	0.002	1.06	0.068	<5	–	–	–
	Nov	–	–	–	–	–	0	–	–	0.029	–	–	<5	–	–	–
	Dec	60	650	–	–	–	0	–	0.4	–	–	0.026	–	–	–	–
1975	Jan	–	–	–	–	–	0	–	–	–	0.38	–	–	–	–	–
	Jul	345	1,600	–	–	–	0	–	–	0.072	0.26	–	–	–	–	–
	Aug	330	1,600	441	190	251	0	336	0.4	0.019	–	0.092	–	–	–	–
	Sep	340	1,600	–	–	–	0	–	3.7	0.032	0.26	0.035	–	–	–	–

*Samples obtained from a nonpumped well with a torpedo sampler.

TABLE B-21. ANALYSIS OF SAMPLES TAKEN FROM WELL PW-8*

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total Hardness mg/l as CaCO$_3$	Ca mg/l as CaCO$_3$	Mg mg/l as CaCO$_3$	CO$_3$ mg/l as CaCO$_3$	HCO$_3$ mg/l as CaCO$_3$	NO$_3$-N mg/l	NO$_2$-N mg/l	NH$_3$-N mg/l	Total P mg/l	COD mg/l	BOD mg/l	TOC mg/l	Standard Coliforms Colonies/ 100 ml
1974	Aug	250	1,400	340	152	188	0	540	<0.1	0.088	0.24	0.028	<5	–	–	–
	Sep	280	1,500	–	–	–	0	–	–	0.022	0.07	0.075	6	–	–	–
	Oct	290	1,500	346	116	230	0	526	0.5	0.026	0.73	0.070	<5	–	–	–
	Nov	–	–	–	–	–	0	–	–	0.366	–	–	8	–	–	–
	Dec	340	1,600	–	–	–	0	–	0.4	–	–	0.035	–	–	–	–
1975	Jan	–	–	–	–	–	0	–	–	–	0.71	–	–	–	–	–
	Jul	335	1,800	–	–	–	0	–	–	0.022	0.10	–	–	–	–	–
	Aug	330	1,800	342	95	247	0	496	0.6	0.018	–	0.029	–	–	–	–
	Sep	330	1,600	–	–	–	0	–	0.5	0.016	0.11	0.023	–	–	–	–

*Samples obtained from a nonpumped well with a torpedo sampler.

TABLE C-1. ANALYSIS OF SAMPLES TAKEN FROM WELL BMW-1

Date		Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1971	Jul	--	5,600	--	--	--	0	--	--
	Aug	1,600	5,600	888	396	492	0	484	--
	Sep	1,600	5,600	892	396	496	0	472	--
	Oct	1,610	5,900	856	336	520	0	520	--
	Nov	1,660	6,000	--	392	--	0	532	--
	Dec	1,670	6,000	876	400	476	0	492	--
1972	Jan	168	6,000	912	400	512	0	524	0
	Feb	1,720	5,900	940	408	532	0	484	--
	Mar	1,650	5,600	--	--	--	0	--	--
	Jun	1,780	6,000	968	416	552	0	492	--
	Jul	1,810	6,000	836	368	468	0	500	--
	Aug	1,810	6,000	880	208	672	0	496	--
	Sep	1,570	6,000	868	336	532	0	472	--
	Oct	1,720	6,000	908	388	520	0	492	--
	Nov	1,400	6,000	680	260	--	0	460	--

PUMP INOPERATIVE

TABLE C-2. ANALYSIS OF SAMPLES TAKEN FROM WELL BMW-2

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1972	Jan	1,750	5,900	948	448	500	0	492	0
	Feb	1,480	5,100	752	368	384	0	492	--
	Mar	1,980	6,200	--	--	--	0	--	0
	Jun	1,850	6,100	1,004	492	512	0	480	--
	Jul	1,840	6,000	988	408	580	0	476	--
	Aug	1,810	6,000	880	208	672	0	496	--
	Sep	1,740	6,000	960	448	512	0	476	--
	Oct	1,970	6,000	1,152	520	632	0	468	--
	Nov	1,850	6,000	1,000	440	560	0	460	--
	Dec	1,800	6,000	1,020	312	708	0	480	--
1973	Jan	1,370	6,000	908	376	532	0	476	--
	Mar	1,660	6,000	928	444	484	0	456	--
	Apr	2,000	6,000	1,128	508	620	0	452	--
	May	2,000	6,000	1,070	480	590	0	450	--
	Jun	1,860	5,500	1,060	490	570	0	460	--
	Jul	1,800	6,000	1,000	460	540	0	480	--
	Aug	2,400	6,000	1,200	572	628	0	436	--
	Sep	1,440	5,000	750	380	370	0	470	--
	Oct	2,050	6,000	1,190	590	600	0	430	-
	Nov	2,020	6,000	1,130	530	600	0	450	--
	Dec	2,060	6,500	1,136	544	592	0	430	--

TABLE C-2 (CONTINUED).

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1974	Jan	2,260	7,000	1,400	600	800	0	430	--
	Feb	1,920	6,000	1,048	530	518	0	460	--
	Apr	1,890	6,000	964	456	408	0	440	--
	May	2,070	7,000	1,080	520	560	0	440	--
	Jun	1,960	6,000	1,044	452	592	0	424	--
	Jul	1,380	4,500	650	310	340	0	460	--
	Aug	1,990	5,000	1,032	484	548	0	436	--
	Sep	1,840	5,000	944	436	508	0	436	--
	Oct	2,082	5,500	1,040	468	572	0	436	--
	Nov	1,480	5,000	740	368	372	0	448	--
1975	Jan	1,460	4,500	760	212	548	0	440	--
	Feb	1,940	5,500	984	408	576	0	404	--
	Mar	1,940	5,500	920	420	500	0	440	--
	May	1,770	5,000	846	392	454	0	432	--
	Jun	1,990	5,500	982	458	524	0	428	--
	Jul	1,785	5,000	854	400	454	0	416	--

TABLE C-3. ANALYSIS OF SAMPLES TAKEN FROM FP-1

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1971	Jul	--	3,450	--	--	--	0	--	--
	Aug	795	3,500	469	240	229	0	468	--
	Sep	870	3,600	496	276	220	0	464	--
	Oct	910	3,800	512	284	228	0	510	3
	Nov	930	3,500	536	288	248	0	504	--
	Dec	960	3,800	560	316	244	0	512	0
1972	Jan	1,020	3,800	640	336	304	0	492	2
	Feb	1,100	4,000	616	336	280	0	488	--
	Mar	1,140	4,000	--	--	--	0	--	8
	Jun	1,240	4,500	728	400	328	0	468	--
SAMPLING TAP REMOVED									
	Oct	1,440	6,000	888	--	--	0	--	--
PUMP NOT RUNNING									
	Dec	1,350	4,500	860	464	396	0	464	--
1973	Jan	1,350	4,000	908	472	432	0	452	--
	Feb	1,380	5,000	904	482	422	0	498	--
	Mar	1,380	5,000	908	508	400	0	444	--
	Apr	1,540	5,500	1,056	536	520	0	416	--

TABLE C-3 (CONTINUED).

Date		Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1973	May	1,600	5,000	1,050	540	510	0	430	--
	Jun	1,600	5,000	1,080	590	490	0	500	--
	Jul	1,620	5,000	1,080	560	520	0	450	0
	Aug	--	--	--	--	--	0	--	48
	Sep	1,670	5,500	1,120	600	520	0	--	1
	Oct	1,700	5,500	1,130	600	530	0	470	5
	Nov	1,660	5,500	1,130	580	550	0	430	C*
1974	Jan	--	--	--	--	--	0	--	0
	Feb	1,220	4,500	520	230	290	0	330	0
	Mar	--	--	--	--	--	0	--	17
PUMP NOT RUNNING									
	May	1,230	4,000	396	140	256	0	260	--
PUMP REMOVED									

*Confluent colonies.

TABLE C-4. ANALYSIS OF SAMPLES TAKEN FROM WELL FP-3

Date	Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1971 Jul	--	6,000	--	--	--	0	--	--
Aug	1,950	6,200	1,240	580	660	0	415	--
Sep	1,350	5,000	920	440	480	0	472	--
PUMPING DISCONTINUED OCT 1971-DEC 1971								
Dec	2,180	6,700	1,440	780	660	0	424	38
1972 Jan	2,120	6,200	1,410	720	690	0	448	9
Feb	2,160	6,800	1,460	730	730	0	436	--
Mar	2,240	6,800	--	--	--	0	--	0
Jun	2,295	7,000	1,630	820	810	0	440	--
Aug	2,590	8,000	1,844	856	988	0	436	--
Sep	2,480	8,000	1,980	942	1,038	0	420	--
PUMPING DISCONTINUED OCT 1972 DUE TO HIGH CHLORIDES-PUMP REMOVED								

TABLE C-5. ANALYSIS OF SAMPLES TAKEN FROM WELL FP-4

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1971	Jul	--	3,800	--	--	--	0	--	--
	Aug	985	4,000	672	316	356	0	490	--
	Sep	650	3,050	480	240	240	0	528	--
	Oct	--	--	--	--	--	0	--	0
	Nov	1,260	4,500	880	480	400	0	512	--
	Dec	1,250	4,600	920	448	472	0	520	0
1972	Jan	970	3,700	684	332	352	0	520	2
	Feb	940	3,700	660	312	348	0	520	--
	Mar	860	3,500	--	--	--	0	--	1
	Jun	980	3,800	700	340	360	0	516	--
	Jul	1,220	5,000	876	372	504	0	500	--
	Aug	1,220	5,000	856	360	496	0	512	--
	Sep	1,170	4,000	864	377	487	0	500	--
	Oct	1,300	5,000	1,024	480	544	0	492	--
	Dec	780	3,500	532	232	300	0	--	--
1973	Jan	1,270	3,500	972	464	508	0	--	--
	Feb	1,640	5,500	1,258	610	648	0	524	--
	Mar	1,860	6,000	1,532	748	784	0	452	--
	Apr	2,280	6,100	1,868	864	1,004	0	444	--

PUMP BEING REPAIRED, APR 1973-MAY 1974

TABLE C-5 (CONTINUED).

Date		Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1974	Jun	3,740	10,000	3,130	1,528	1,602	0	410	--
	Jul	3,720	10,000	3,080	1,480	1,600	0	400	1
	Aug	3,420	10,000	3,090	1,515	1,575	0	390	0
	Sep	3,225	8,000	2,700	1,352	1,648	0	390	--
	Oct	--	--	--	--	--	0	--	0
1975	Jan	2,270	6,000	1,932	712	1,220	0	436	--
	Feb	2,340	6,000	1,916	912	1,004	0	456	0
	Mar	2,560	6,000	1,936	936	1,000	0	440	--

PUMPING DISCONTINUED APR 1975 DUE TO HIGH CHLORIDES

TABLE C-6. ANALYSIS OF SAMPLES TAKEN FROM WELL FP-7

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1971	Jun	--	2,700	--	--	--	0	--	--
	Jul	--	2,700	--	--	--	0	--	--
	Aug	470	2,650	362	164	198	0	563	--
	Sep	460	2,600	348	164	184	0	568	--
	Oct	480	2,700	348	196	152	0	620	1
	Nov	480	2,600	364	164	200	0	620	--
	Dec	470	2,600	360	168	192	0	612	0
1972	Jan	480	2,550	352	172	180	0	620	1
	Feb	470	2,600	344	188	156	0	636	--
	Mar	380	2,400	--	--	--	0	--	21
	Jun	470	2,600	360	172	188	0	612	--
	Jul	500	2,500	396	168	228	0	620	--
	Aug	530	2,600	372	168	204	0	614	--
	Sep	510	2,600	388	156	232	0	616	--
	Oct	520	2,600	388	164	224	0	612	--
	Dec	460	2,600	368	164	204	0	624	--
1973	Jan	350	2,000	408	184	224	0	632	--
	Feb	480	2,600	388	176	212	0	700	--
	Mar	450	2,600	936	192	744	0	596	--
	Apr	500	2,600	404	204	200	0	624	--

TABLE C-6 (CONTINUED).

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1973	May	500	2,600	420	230	190	0	600	--
	Jun	500	2,400	400	200	200	0	590	--
	Jul	540	2,400	430	190	240	0	600	0
	Aug	480	2,600	430	190	240	0	580	0
	Sep	490	2,800	380	200	180	0	580	4
	Oct	490	2,600	420	200	220	0	590	0
	Nov	480	2,440	392	200	192	0	580	2
1974	Jan	510	2,440	416	192	224	0	580	0
	Feb	540	2,800	416	196	220	0	580	0
	May	550	2,800	448	212	236	0	572	1
	Jun	580	2,600	418	194	224	0	578	2
	Jul	560	2,700	416	200	216	0	572	54
	Aug	590	2,600	--	--	--	0	--	2
	Sep	710	2,400	500	200	300	0	578	--
	Oct	--	--	--	--	--	0	--	6
1975	Jan	620	2,600	488	240	248	0	572	--
	Feb	600	2,600	476	216	260	0	596	5
	Mar	610	2,500	440	192	248	0	604	--
	Jun	608	2,600	481	229	252	0	580	--
	Jul	--	--	--	--	--	0	--	2

TABLE C-7. ANALYSIS OF SAMPLES TAKEN FROM WELL FP-9

Date		Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1971	Jul	--	2,200	--	--	--	0	--	--
	Aug	305	2,150	420	170	250	0	586	--
	Sep	270	1,800	340	160	180	0	520	--
	Oct	360	2,350	484	232	252	0	710	--
	Nov	290	1,950	400	188	212	0	628	--
	Dec	340	2,050	384	168	216	0	612	--
1972	Jan	330	1,920	400	180	220	0	620	--
	Feb	330	2,100	400	204	196	0	604	--
	Mar	305	1,900	--	--	--	0	--	--
	Jun	310	2,000	368	168	200	0	616	--
	Jul	300	1,900	372	176	196	0	612	--
	Aug	330	2,000	388	168	220	0	628	--
	Sep	350	2,000	400	120	280	0	636	--
	Oct	320	2,000	420	160	260	0	640	--
	Dec	370	2,200	452	196	256	0	692	0
1973	Jan	340	2,000	492	188	304	0	--	0
	Feb	330	2,200	440	206	234	0	810	--
	Mar	330	2,200	432	200	232	0	652	2
	Apr	380	2,100	460	208	252	0	672	--
	May	360	2,200	460	220	240	0	630	--
	Jun	360	2,000	460	260	200	0	650	--

TABLE C-7 (CONTINUED).

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1973	Jul	340	2,000	420	230	190	0	610	77
	Aug	370	2,200	480	220	260	0	640	0
	Sep	370	2,200	470	240	230	0	650	0
	Oct	--	--	--	--	--	0	--	6
PIPELINE BEING REPAIRED-PUMP OFF									
1974	Jan	300	1,800	408	168	240	0	576	0
	Feb	300	1,900	392	172	220	0	568	0
	Mar	--	--	--	--	--	0	--	0
	May	310	2,000	372	180	192	0	--	0
	Jun	310	1,900	358	162	196	0	560	0
	Jul	300	2,000	324	160	164	0	556	0
	Aug	330	1,900	408	180	228	0	584	7
	Sep	340	1,900	388	180	208	0	596	--
	Oct	--	--	--	--	--	0	--	0
PUMPING DISCONTINUED OCT 1974-JAN 1975									
1975	Jan	300	1,700	368	180	188	0	496	0
	Feb	310	1,900	380	172	208	0	544	0
	Mar	330	1,800	376	172	204	0	568	--

TABLE C-8. ANALYSIS OF SAMPLES TAKEN FROM WELL F-1

Date		Chlorides mg/l	Conductivity µmhos/cm² at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1971	Jul	--	730	--	--	--	0	--	--
	Aug	99	900	371	168	203	0	328	--
	Sep	110	900	388	208	180	0	338	--
	Oct	110	950	384	212	172	0	--	--
	Nov	110	920	400	218	182	0	364	--
	Dec	130	1,000	400	220	180	0	364	--
1972	Jan	130	920	420	216	204	0	368	--
	Feb	130	1,000	434	224	210	0	384	--
	Jul	100	800	372	184	188	0	348	--
	Aug	110	800	368	184	184	0	352	--
	Sep	100	800	364	192	172	0	348	--
	Oct	100	900	340	184	156	0	--	--
	Nov	120	800	368	152	216	0	--	--
	Dec	100	750	400	188	212	0	--	--
1973	Jan	100	650	376	184	192	0	--	--
	Feb	110	850	364	190	174	0	358	--
	Mar	100	850	368	192	174	0	316	--

SAMPLING TAP REMOVED APR 1973

TABLE C-9. ANALYSIS OF SAMPLES TAKEN FROM WELL F-2

Date		Chlorides mg/l	Conductivity µmhos/cm² at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1972	Feb	105	850	312	164	148	0	368	--
	Jul	110	850	308	160	148	0	364	--
	Aug	130	850	320	168	152	0	372	--
	Sep	100	900	332	172	160	0	384	--
	Oct	110	800	368	180	188	20	348	--
	Nov	120	900	340	132	208	0	400	--
	Dec	110	900	344	208	136	0	382	--
1973	Jan	140	850	380	204	176	0	388	--
	Feb	90	950	312	190	122	0	414	--
	Mar	110	900	320	118	202	0	352	--
	Apr	180	900	332	196	136	0	364	--
	May	120	900	340	208	132	0	356	--
	Jun	100	850	344	200	144	0	368	--
	Jul	100	875	352	196	156	0	460	--
	Aug	110	950	344	208	136	0	364	--
	Sep	110	1,000	356	212	144	0	368	--
	Oct	110	950	356	220	136	0	368	--
	Nov	100	1,000	376	228	148	0	380	--
	Dec	110	1,000	288	228	60	0	384	--
1974	Jan	110	900	320	204	116	0	384	--
	Feb	100	950	336	204	132	0	364	--

TABLE C-9 (CONTINUED).

Date	Chlorides mg/1	Conductivity μmhos/cm^2 at 25° C	Total hardness mg/1 as $CaCO_3$	Ca mg/1 as $CaCO_3$	Mg mg/1 as $CaCO_3$	CO_3 mg/1 as $CaCO_3$	HCO_3 mg/1 as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1974 May	90	900	352	244	208	0	368	--
Jun	90	900	318	152	166	0	380	--
Jul	100	950	320	204	116	0	368	--
Aug	110	950	424	196	228	0	372	--
Sep	105	1,000	356	200	156	0	372	--
Oct	116	900	372	220	152	0	388	--
Nov	140	1,000	452	224	228	0	420	--
1975 Jan	230	1,050	456	256	200	0	376	--
Feb	170	1,050	412	200	212	0	388	--
Mar	160	1,000	376	220	156	0	372	--
May	150	1,050	376	229	147	0	360	--
Jun	160	1,000	396	232	164	0	372	--
Jul	152	950	396	229	167	0	374	--

TABLE C-10. ANALYSIS OF SAMPLES TAKEN FROM WELL GG-6

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1971	Jul	--	2,200	--	--	--	0	--	--
	Aug	290	2,200	402	198	204	0	596	--
	Sep	260	1,750	324	164	160	0	480	--
	Oct	310	2,200	396	192	204	0	685	--
	Nov	320	2,200	404	208	196	0	652	--
	Dec	330	2,200	400	192	208	0	692	--
1972	Jan	330	2,100	400	192	208	0	688	--
	Feb	310	1,800	388	176	212	0	660	--
	Jun	330	2,100	432	196	236	0	644	--
	Jul	300	2,000	404	172	232	0	648	--
	Aug	300	2,000	408	173	235	0	644	--
	Sep	310	2,000	404	160	244	0	648	--
	Oct	330	2,000	392	164	228	0	620	--
	Nov	310	2,000	392	156	236	0	612	--
	Dec	300	2,000	380	80	300	0	640	--
1973	Jan	330	2,000	332	160	172	0	632	--
	Apr	400	2,200	468	200	268	0	660	--
	May	400	2,200	480	220	260	0	670	--

WELL DRY, JUN 1973-DEC 1974

TABLE C-10 (CONTINUED).

Date	Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1975 Jan	700	3,000	992	360	632	0	464	--
Feb	650	3,000	920	384	536	0	476	--
Mar	570	2,000	692	248	444	0	512	--

ENTRANCE TO WELL SEALED UP, SAMPLING IMPOSSIBLE

TABLE C-11. ANALYSIS OF SAMPLES TAKEN FROM WELL MB-4

Date		Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1971	June	--	3,400	--	--	--	0	--	--
	Aug	640	3,050	356	168	188	0	524	--
	Sep	1,040	4,500	514	228	186	0	524	--
	Nov	670	3,200	372	180	182	0	548	--
	Dec	670	3,200	368	168	200	0	528	--
1972	Jan	1,050	4,200	560	228	332	12	548	--
	Feb	1,060	4,200	516	220	296	0	540	--
	Mar	920	3,900	--	--	--	0	--	--
	Jun	680	3,300	364	172	192	0	552	--
	Jul	920	4,000	472	196	276	0	552	--
	Aug	680	3,000	360	160	200	0	544	--
	Sep	770	3,500	396	156	240	0	540	--
	Oct	730	3,000	396	160	236	0	544	--
1973	Feb	710	3,500	420	198	222	0	610	--
	Mar	750	3,500	432	200	232	0	524	--
	Apr	1,140	4,900	600	276	324	0	528	--
	May	1,440	5,000	700	290	410	0	510	--
	Jun	1,200	4,250	610	300	310	0	530	--
	Jul	1,240	5,000	640	280	360	0	530	0
	Aug	1,540	5,500	776	336	440	0	508	1
	Sep	1,270	5,000	650	340	310	0	510	>100

TABLE C-11 (CONTINUED).

Date		Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1973	Oct	1,330	5,000	690	280	410	0	510	0
	Nov	1,500	5,500	748	324	424	0	500	4
	Dec	1,350	5,500	680	288	392	0	516	0
1974	Jan	990	4,000	524	240	284	0	524	1
	Feb	1,200	5,000	650	280	370	0	520	9
	Mar	--	--	--	--	--	0	--	0
	May	1,450	6,000	700	304	396	0	500	1
	Jun	1,120	4,000	578	224	354	0	522	0
	Jul	1,220	4,500	610	250	360	0	520	0
	Aug*	600	2,800	404	172	232	0	528	0
	Sep	670	2,600	452	168	284	0	516	0
	Oct	1,410	4,500	708	296	412	0	514	0
	Nov	1,020	4,000	532	228	304	0	448	--
1975	Jan	1,340	4,500	664	260	404	0	500	--
	Feb	1,240	4,500	584	256	328	0	516	--
	Mar	1,400	4,500	600	284	352	0	520	8
	Apr	--	--	--	--	--	0	--	0
	May	1,310	4,500	621	256	365	0	432	--
	Jun	1,280	4,500	621	261	360	0	512	0
	Jul	1,005	3,750	513	217	296	0	517	--
	Aug	--	--	--	--	--	0	--	0

*Water contaminated with some type of petroleum product that smells like kerosene, Aug 1974-Jul 1975.

TABLE C-12. ANALYSIS OF SAMPLES TAKEN FROM WELL MB-5

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1971	Nov	710	3,200	340	168	172	0	560	--
	Dec	710	3,400	328	156	172	0	530	--
1972	Jan	710	3,400	340	168	172	0	552	--
	Feb	710	3,200	348	164	184	0	528	--
	Mar	740	3,400	--	--	--	0	--	--
PUMP BROKEN APR 1972-APR 1974									
1974	May	690	3,500	364	172	192	0	524	0
	Jun	690	3,000	320	152	168	0	550	--
	Jul	700	3,000	328	164	164	0	524	0
	Aug	680	2,800	346	144	202	0	516	--
	Sep	610	2,800	292	168	124	0	510	0
	Oct	748	2,800	372	164	208	0	520	--
	Nov	730	3,000	376	196	180	0	524	--
1975	Mar	760	2,800	340	168	172	0	540	--
	May	760	2,800	361	166	195	0	508	--
	Jun	--	--	--	--	--	0	--	21
	Jul	742	3,000	384	186	198	0	513	--

TABLE C-13. ANALYSIS OF SAMPLES TAKEN FROM WELL MB-29

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1971	Aug	920	4,000	372	164	208	0	532	--
	Sep	890	4,000	376	164	212	0	532	--
	Oct	960	4,000	384	176	208	0	570	--
	Nov	930	4,000	384	172	212	0	564	--
	Dec	970	3,700	388	168	220	0	560	--
1972	Jan	1,000	4,000	400	192	208	0	542	--
	Feb	1,080	4,500	432	172	260	0	568	--
	Mar	1,000	4,000	--	--	--	0	--	--
	Jun	940	4,000	356	164	192	0	536	--
	Jul	980	4,000	400	152	248	0	568	--
	Oct	890	4,000	368	140	228	0	580	--
	Nov	1,130	4,000	436	160	276	0	572	--
	Dec	980	4,000	408	148	260	0	568	--
1973	Feb	950	4,000	396	180	216	0	--	--
	Mar	990	4,000	400	180	220	0	528	--
	Apr	1,060	4,000	428	184	244	0	544	--
	May	1,040	4,000	430	190	240	0	530	--
	Jun	1,040	3,750	430	210	220	0	540	--
	Jul	1,060	4,000	440	230	210	0	540	0
	Aug	1,020	4,000	440	192	248	0	524	4
	Sep	1,450	4,500	440	210	230	0	520	--

TABLE C-13 (CONTINUED).

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	Standard coliforms Colonies/ 100 ml
1973	Oct	1,030	4,000	440	230	210	0	540	90
	Nov	1,060	4,000	450	240	210	0	540	0
	Dec	1,090	5,000	448	208	240	0	532	0
1974	Jan	1,080	4,000	500	220	280	0	550	3
	Feb	1,060	4,500	412	188	224	0	512	1
	May	1,090	4,500	404	188	216	0	536	--
	Jun	1,100	4,000	366	140	226	0	494	>100
	Jul	--	--	--	--	--	0	--	>100

TABLE D-1. ANALYSIS OF STREAM SAMPLES TAKEN FROM RIVER GUT-CENTERLINE ROAD STATION

Date		Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$
1971	Jul	--	1,250	--	--	--	0	--
	Aug	145	1,300	386	156	230	0	558
	Sep	80	700	236	112	124	0	244
	Oct	90	680	224	112	112	0	270
	Nov	100	930	272	140	132	0	384
	Dec	140	1,100	312	140	172	0	424
1972	Jan	150	1,090	320	152	168	0	448
	Feb	170	1,150	316	142	174	0	444
	Mar	120	980	--	--	--	0	--
	Jul	160	1,300	360	152	208	0	516
	Aug	180	1,300	356	140	216	0	532
NO NATURAL FLOW IN RIVER GUT AT THIS STATION SEPT 1972-OCT 1974								
1974	Nov	100	580	248	172	76	0	188
1975	Jan	200	1,300	484	236	248	0	484
	Feb	180	1,300	440	232	208	0	520

TABLE D-2. ANALYSIS OF STREAM SAMPLES TAKEN FROM RIVER GUT-FOUNTAIN STATION

Date		Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$
1971	Jul	--	980	--	--	--	0	--
	Aug	125	950	450	228	222	0	428
	Sep	150	980	448	280	168	0	348
	Oct	130	900	400	224	176	0	358
	Nov	100	800	332	178	154	0	352
	Dec	130	1,000	400	220	180	0	364
1972	Jan	55	580	276	176	100	0	304
	Mar	60	650	--	--	--	0	--
NO NATURAL FLOW IN RIVER GUT AT THIS STATION APRIL 1972-OCT 1974								
1974	Nov	120	650	272	160	112	0	180
1975	Jan	130	800	444	248	196	0	308
	Feb	140	850	440	236	204	0	304
	Mar	170	950	424	224	200	0	300
	May	200	1,000	508	283	225	0	316
	Jun	210	1,000	523	287	236	0	336

TABLE D-3. ANALYSIS OF STREAM SAMPLES TAKEN FROM RIVER GUT-GOLDEN GROVE STATION

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$
1971	Jul	--	1,700	--	--	--	0	--
	Sep	220	1,450	340	132	208	0	472
	Oct	95	740	232	112	120	0	272
	Nov	150	1,220	320	156	164	0	440
	Dec	220	1,400	376	180	196	0	544
1972	Jan	230	1,500	380	176	204	0	--
	Feb	240	1,600	380	168	212	0	544
	Mar	180	1,280	--	--	--	-	--

NO FLOW IN RIVER GUT AT THIS STATION FROM APR 1972-OCT 1974

TABLE D-4. ANALYSIS OF STREAM SAMPLES TAKEN FROM RIVER GUT-HOLY CROSS STATION

Date		Chlorides mg/l	Conductivity μmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$
1971	Aug	180	1,400	437	208	229	0	597
	Sep	170	1,250	404	208	196	0	436
	Oct	95	750	248	124	124	0	300
	Nov	90	900	284	160	124	0	364
	Dec	110	950	316	156	160	0	376
1972	Jan	150	1,120	356	180	176	0	436
	Feb	165	1,200	376	180	186	0	444
	Mar	110	950	--	--	--	0	--
NO NATURAL FLOW IN RIVER GUT AT THIS STATION FROM APR 1972-OCT 1974								
1974	Nov	100	650	268	136	132	0	200
1975	Jan	170	1,100	476	216	260	0	404
	Feb	150	1,100	416	188	228	0	380
	Mar	150	1,000	392	188	204	0	380
	May	200	1,300	489	245	244	0	508
	Jun	220	1,400	528	242	286	0	532

TABLE D-5. ANALYSIS OF STREAM SAMPLES TAKEN FROM RIVER GUT-RIVER STATION

Date		Chlorides mg/l	Conductivity µmhos/cm^2 at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$
1971	Jul	--	980	--	--	--	0	--
	Aug	85	920	339	156	183	0	464
	Sep	90	700	272	124	148	0	280
	Oct	60	500	180	92	88	0	198
	Nov	50	560	220	108	112	0	252
	Dec	70	660	236	120	116	0	268
1972	Jan	80	750	288	152	136	0	332
	Feb	100	770	284	144	140	0	316
	Mar	75	640	--	--	--	0	--
	Jul	70	500	312	144	168	0	404
	Aug	90	850	320	152	168	0	408
NO NATURAL FLOW IN RIVER GUT AT THIS STATION FROM SEPT 1972-OCT 1974								
1974	Nov	80	480	212	108	104	0	152
1975	Jan	190	800	368	192	176	0	324
	Feb	130	800	372	180	196	0	316
	Mar	150	900	384	176	208	0	320
	May	150	1,000	423	198	225	0	396
	Jun	150	1,100	433	221	212	0	420
	Jul	152	1,000	442	225	217	0	433

TABLE D-6. ANALYSIS OF STREAM SAMPLES TAKEN FROM RIVER GUT-USGS STATION

Date		Chlorides mg/l	Conductivity μmhos/cm² at 25° C	Total hardness mg/l as $CaCO_3$	Ca mg/l as $CaCO_3$	Mg mg/l as $CaCO_3$	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$
1971	Aug	255	1,800	394	172	222	0	672
	Sep	140	960	284	152	132	0	300
	Oct	105	750	240	108	132	0	287
	Nov	130	1,100	300	152	148	0	408
	Dec	210	1,550	376	164	202	0	516
1972	Jan	200	1,400	364	180	184	0	516
	Feb	225	1,500	348	160	188	0	536
	Mar	170	1,270	--	--	--	0	--
	Apr	250	1,800	400	160	240	0	668
	Jun	190	1,600	336	152	184	0	580
	Jul	310	2,000	400	128	272	0	648

NO NATURAL FLOW IN RIVER GUT AT THIS STATION FROM AUG 1972-OCT 1974

TABLE E-1. OPERATING DATA FOR THE AWWTP, JANUARY-OCTOBER, 1974

		Influent Data												
Time Period		BOD mg/l	COD mg/l	NO_3-N mg	NH_3-N	Total P	Chlorides	Conductivity	Total Hardness	Ca	Mg	CO_3	HCO_3	pH
1974	Range													
Jan-Feb	Upper	79	280	0.8	25.5	12.0	500	2,000	274	100	180	0	428	--
	Lower	56	102	0.2	10.5	6.8	340	1,500	168	56	92	0	316	--
	Mean	68	194	0.4	17.8	10.8	409	1,763	220	83	137	0	355	--
	Std Dev	9	46	0.3	5.5	2.8	48	48	35	13	28	--	37	--
1974	Range													
Mar-Apr	Upper	--	203	1.4	27.5	18.7	480	2,000	296	112	184	0	372	7.7
	Lower	--	128	0.3	11.6	9	420	1,500	240	96	132	0	316	7.2
	Mean	--	168	0.6	19.5	12.6	449	1,775	261	105	156	0	344	7.4
	Std Dev	--	27	0.5	6.5	4.2	24	206	26	8	24	--	26	0.2
1974	Range													
May-Jun	Upper	184	296	2.7	34.5	41.0	680	2,500	360	160	208	0	356	8.1
	Lower	56	158	0.1	15.0	10.9	430	1,400	180	88	80	0	264	7.2
	Mean	118	219	0.6	24.9	19.5	486	1,990	283	120	163	0	321	7.6
	Std Dev	49	46	0.9	6.3	12.1	67	355	61	25	42	--	38	0.4
1974	Range													
Jul-Aug	Upper	289	259	0.3	30.5	12.6	790	2,600	416	152	264	0	356	7.6
	Lower	56	96	0.1	14.0	7.6	300	1,300	260	100	152	0	248	7.2
	Mean	140	215	0.2	25.3	10.3	480	1,817	318	125	193	0	312	7.4
	Std Dev	27	53	0.1	9.1	2.0	119	358	59	19	42	--	39	0.1
1974	Range													
Sep-Oct	Upper	143	370	1.0	44.5	11.8	980	2,800	808	232	576	0	336	7.8
	Lower	19	63	0.3	8.0	3.0	301	1,200	248	96	116	0	164	6.8
	Mean	107	209	0.6	22.7	8.0	453	1,677	348	133	204	0	274	7.3
	Std Dev	26	76	0.4	12.4	3.0	153	320	177	41	142	--	51	0.2
1974 Jan-Oct	Mean	113	206	0.6	22.6	12.3	456	1,778	289	114	172	0	318	7.4

TABLE E-2. OPERATING DATA FOR THE AWWTP, JANUARY-OCTOBER, 1974

Time Period		Effluent Data									Aeration Tank		AWWTP Electric Power
		BOD	COD	NO_3-N	NH_3-N	Total P	CO_3 mg/l as $CaCO_3$	HCO_3 mg/l as $CaCO_3$	pH	Turbidity	MLSS	SVI	
		mg/l	mg/l	mg/l	mg/l	mg/l				FTU	mg/l	mg/l	kwh
1974	Range												
Jan-Feb	Upper	10	43	24	6.5	9.4	0	236	7.2	5	1,980	404	27,120
	Lower	2	5	4.8	2.0	0.7	0	196	7.2	0.6	300	55	
	Mean	5	26	12.6	3.6	5.2	0	199	7.2	1.5	922	104	
	Std Dev	4	11	8.5	1.8	4.3	–	33	7.2	0.9	482	68	
1974	Range												
Mar-Apr	Upper	–	76	16.8	6.0	12.2	0	220	7.3	1.8	1,620	250	62,160
	Lower	–	20	1.5	1.5	7.9	0	152	6.5	0.1	545	39	
	Mean	–	39	9.0	3.4	9.8	0	181	6.8	1.3	962	84	
	Std Dev	–	19	6.3	1.9	1.8	–	31	0.2	0.5	328	54	
1974	Range												
May-Jun	Upper	11	64	19.8	18.0	11.0	0	140	7.7	3.0	4,630	337	69,720
	Lower	2	7	6.5	1.5	5.1	0	40	6.7	0.4	395	31	
	Mean	6	25	12.1	9.3	8.8	0	92	7.0	1.4	1,707	81	
	Std Dev	4	13	4.3	7.0	2.3	–	33	0.3	0.6	780	56	
1974	Range												
Jul-Aug	Upper	25	53	21.6	18.0	10.5	0	72	6.8	1.5	3,850	96	62,400
	Lower	6	18	9.6	3.5	4.6	0	44	6.4	0.8	490	22	
	Mean	14	37	16.7	9.6	6.7	0	53	6.5	1.0	1,638	64	
	Std Dev	7	10	5.0	5.7	2.0	–	10	0.1	0.3	951	15	
1974	Range												
Sep-Oct	Upper	32	48	20.2	16.5	6.4	0	260	7.2	3.0	2,190	62	60,960
	Lower	11	4	0.1	<0.1	1.1	0	40	5.7	1.0	760	27	
	Mean	22	31	11.8	6.2	4.7	0	95	6.6	1.4	1,334	46	
	Std Dev	8	13	9.0	5.3	1.7	–	69	0.4	0.5	326	9	
1974 Jan-Oct	Mean	12	31	12.9	6.8	9.0	0	123	6.7	1.3	1,351	75	28,236*

*Average kwh/month.

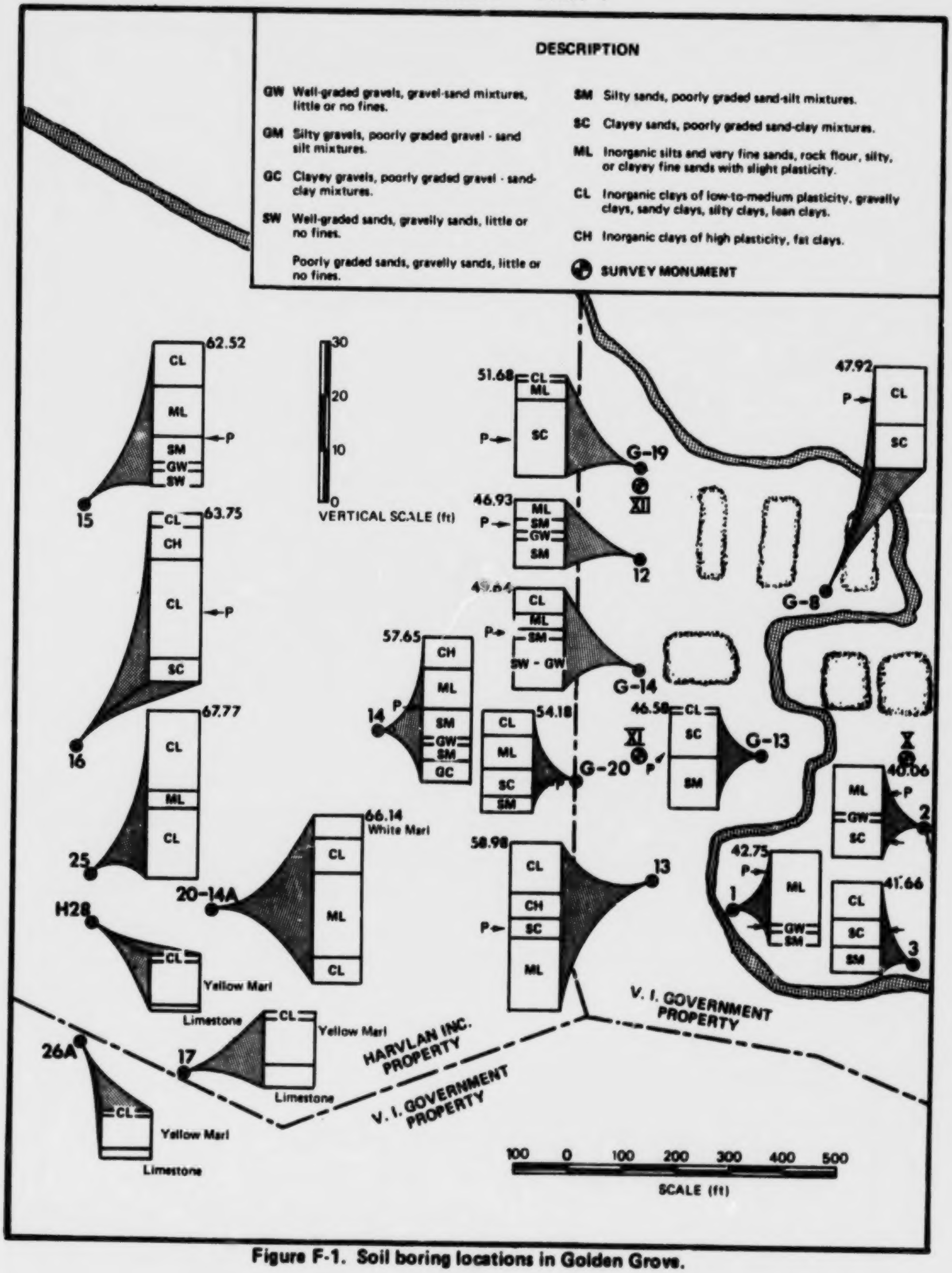
DESCRIPTION
GW Well-graded gravels, gravel-sand mixtures, little or no fines.
GM Silty gravels, poorly graded gravel - sand silt mixtures.
GC Clayey gravels, poorly graded gravel - sand-clay mixtures.
SW Well-graded sands, gravelly sands, little or no fines.
Poorly graded sands, gravelly sands, little or no fines.
SM Silty sands, poorly graded sand-silt mixtures.
SC Clayey sands, poorly graded sand-clay mixtures.
ML Inorganic silts and very fine sands, rock flour, silty, or clayey fine sands with slight plasticity.
CL Inorganic clays of low-to-medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
CH Inorganic clays of high plasticity, fat clays.
SURVEY MONUMENT
VERTICAL SCALE (ft)
0
10
20
30
15
16
25
H28
26A
17
20-14A
14
12
13
G-19
G-14
G-20
G-13
G-8
1
2
3
62.52
63.75
67.77
66.14
White Marl
Yellow Marl
Limestone
57.65
51.68
46.93
54.18
46.58
58.98
47.92
40.06
42.75
41.66
P
XI
XII
X
HARVLAN INC. PROPERTY
V. I. GOVERNMENT PROPERTY
V. I. GOVERNMENT PROPERTY
SCALE (ft)
100
0
100
200
300
400
500

Figure F-1. Soil boring locations in Golden Grove.

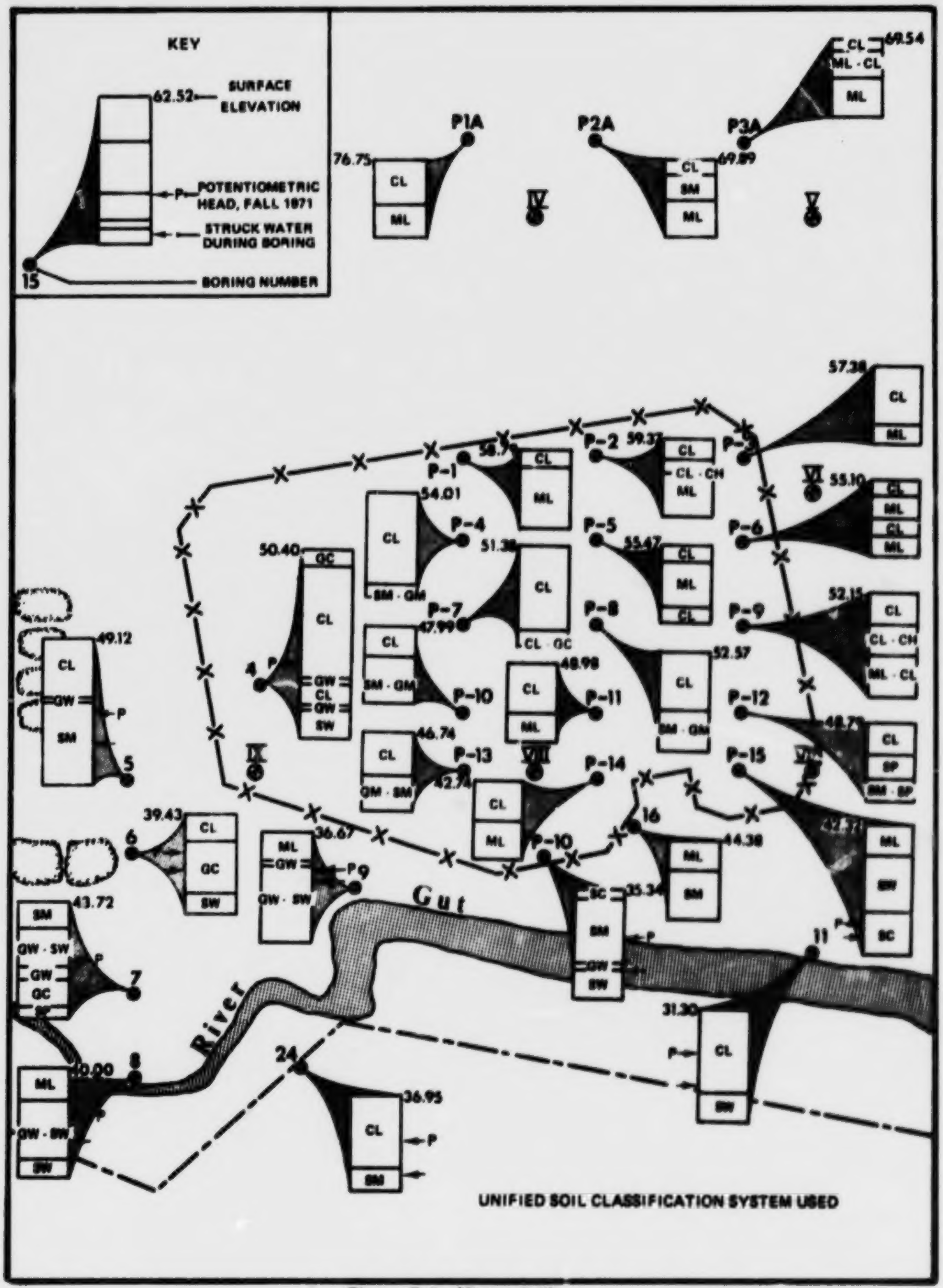
KEY
62.52 SURFACE ELEVATION
P POTENTIOMETRIC HEAD, FALL 1971
STRUCK WATER DURING BORING
15 BORING NUMBER
P1A
P2A
P3A
76.75
CL
ML
69.89
SM
69.54
ML - CL
IV
V
VI
VII
VIII
IX
57.38
59.37
58.7
P-1
P-2
P-3
P-4
P-5
P-6
P-7
P-8
P-9
P-10
P-11
P-12
P-13
P-14
P-15
CL - CH
54.01
51.38
55.47
55.10
52.15
52.57
48.98
47.99
48.72
46.74
42.74
42.71
44.38
35.34
36.67
39.43
43.72
49.12
50.40
31.30
36.95
GC
SM - GM
CL - GC
ML - CL
GW
SW
SP
SM - SP
GM - SM
GW - SW
SC
4
5
6
7
8
9
11
16
24
Gut
River
UNIFIED SOIL CLASSIFICATION SYSTEM USED

Figure F-1. (Extended)

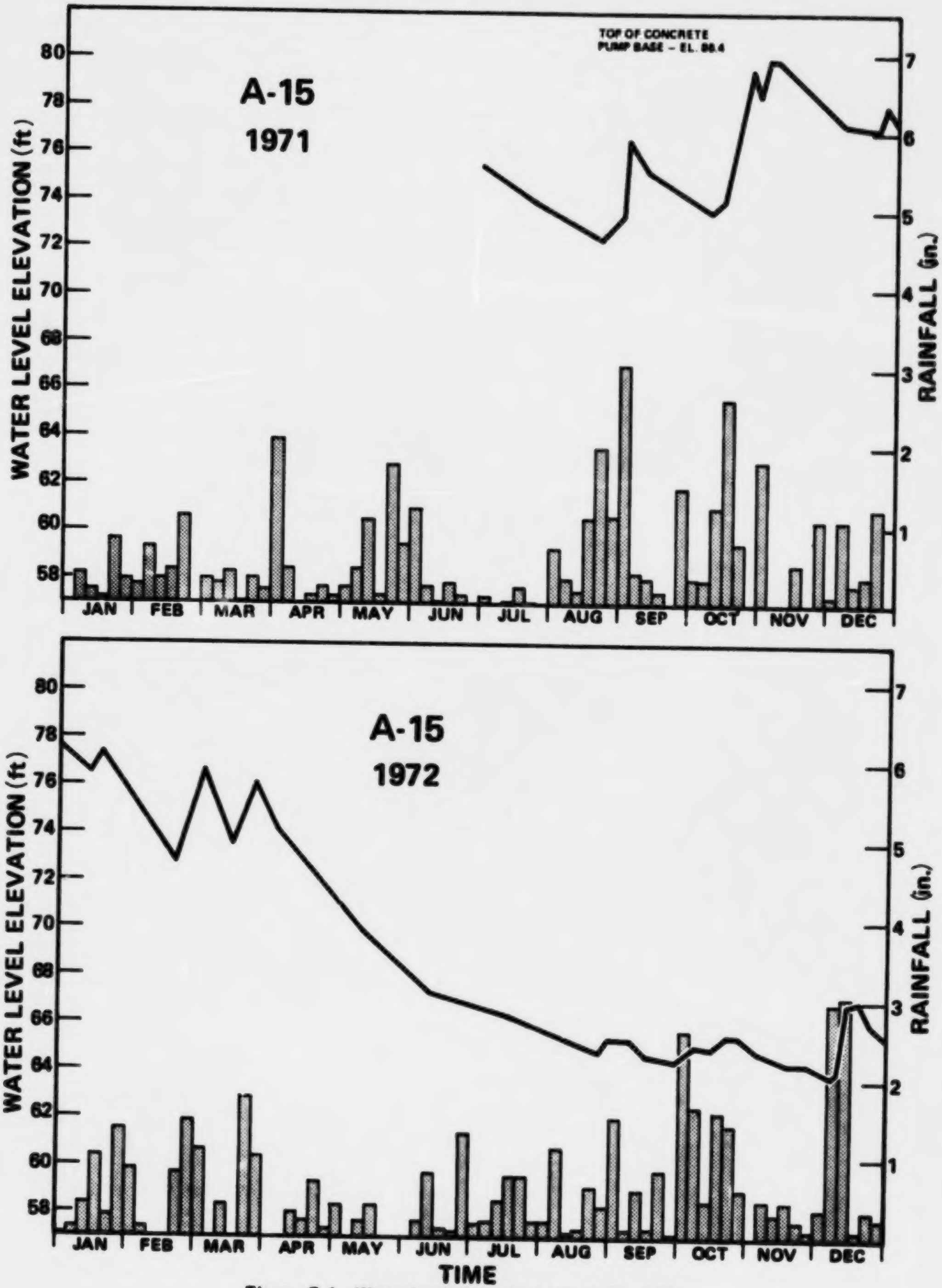

Figure G-1. Water levels in well A-15, 1971-1972.

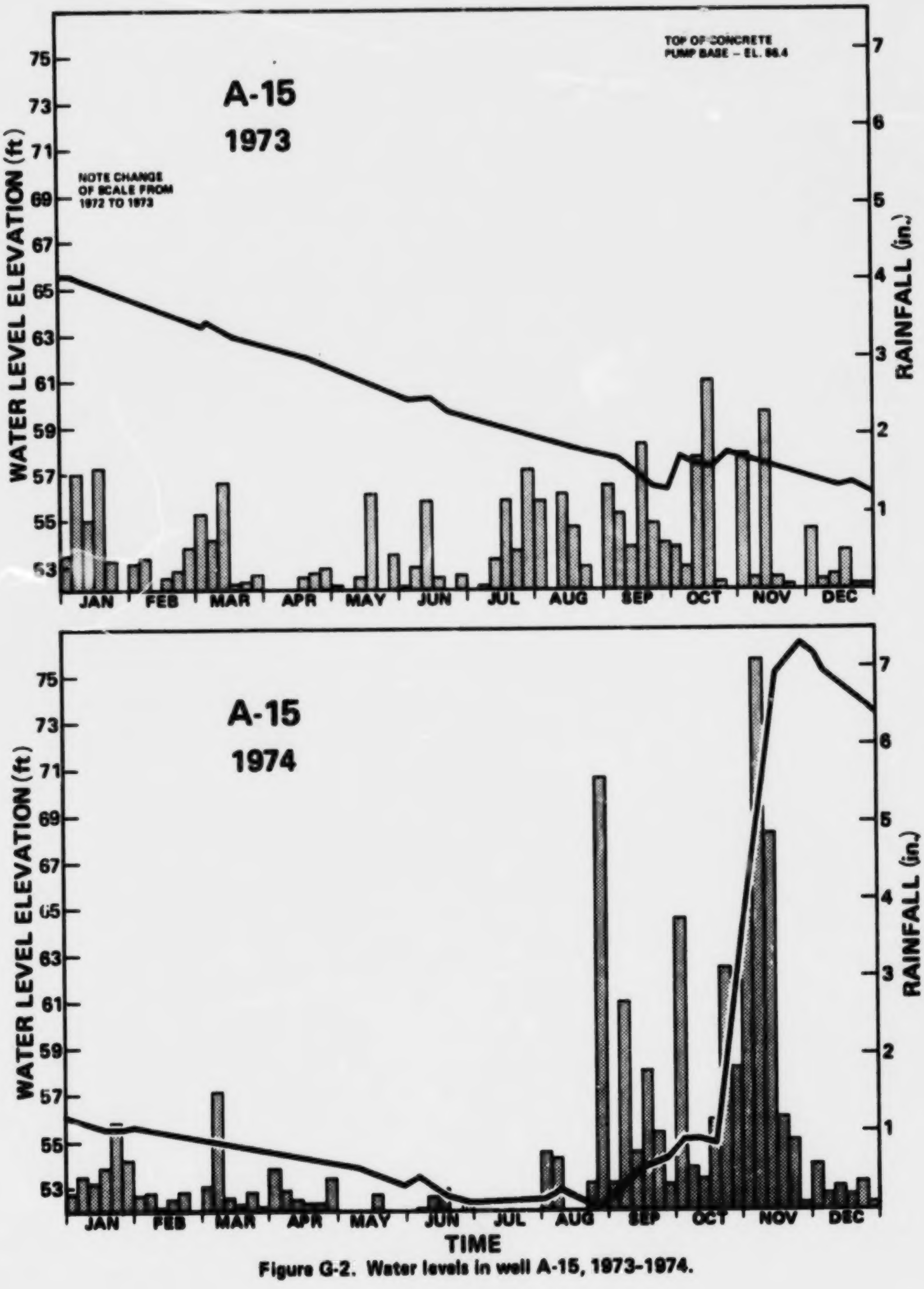

Figure G-2. Water levels in well A-15, 1973-1974.

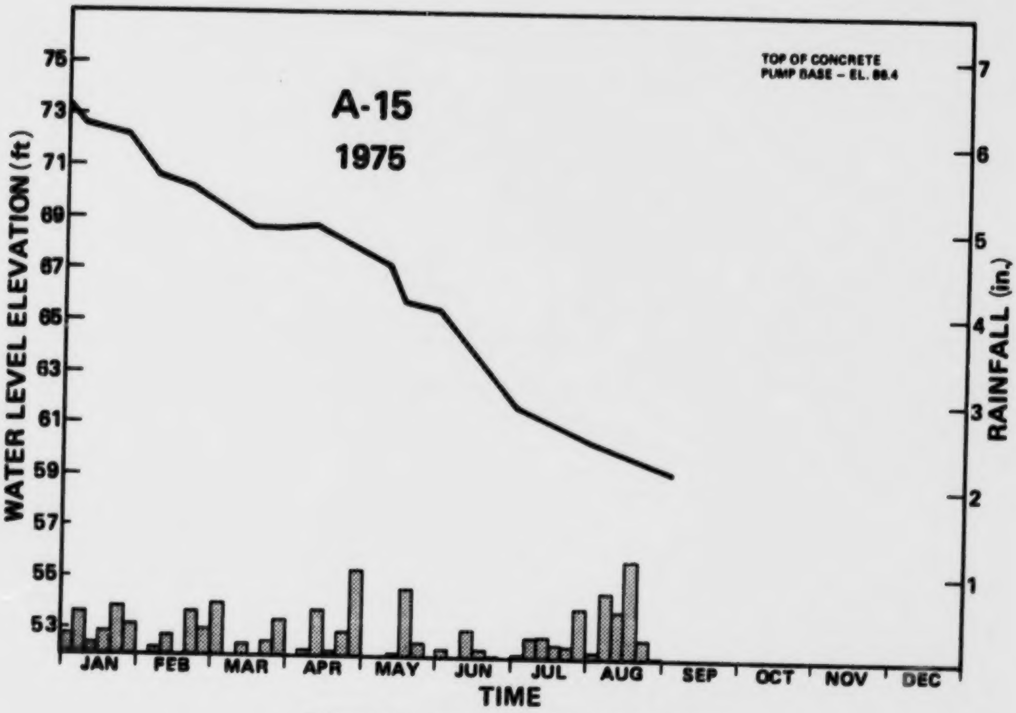

Figure G-3. Water levels in well A-15, 1975.

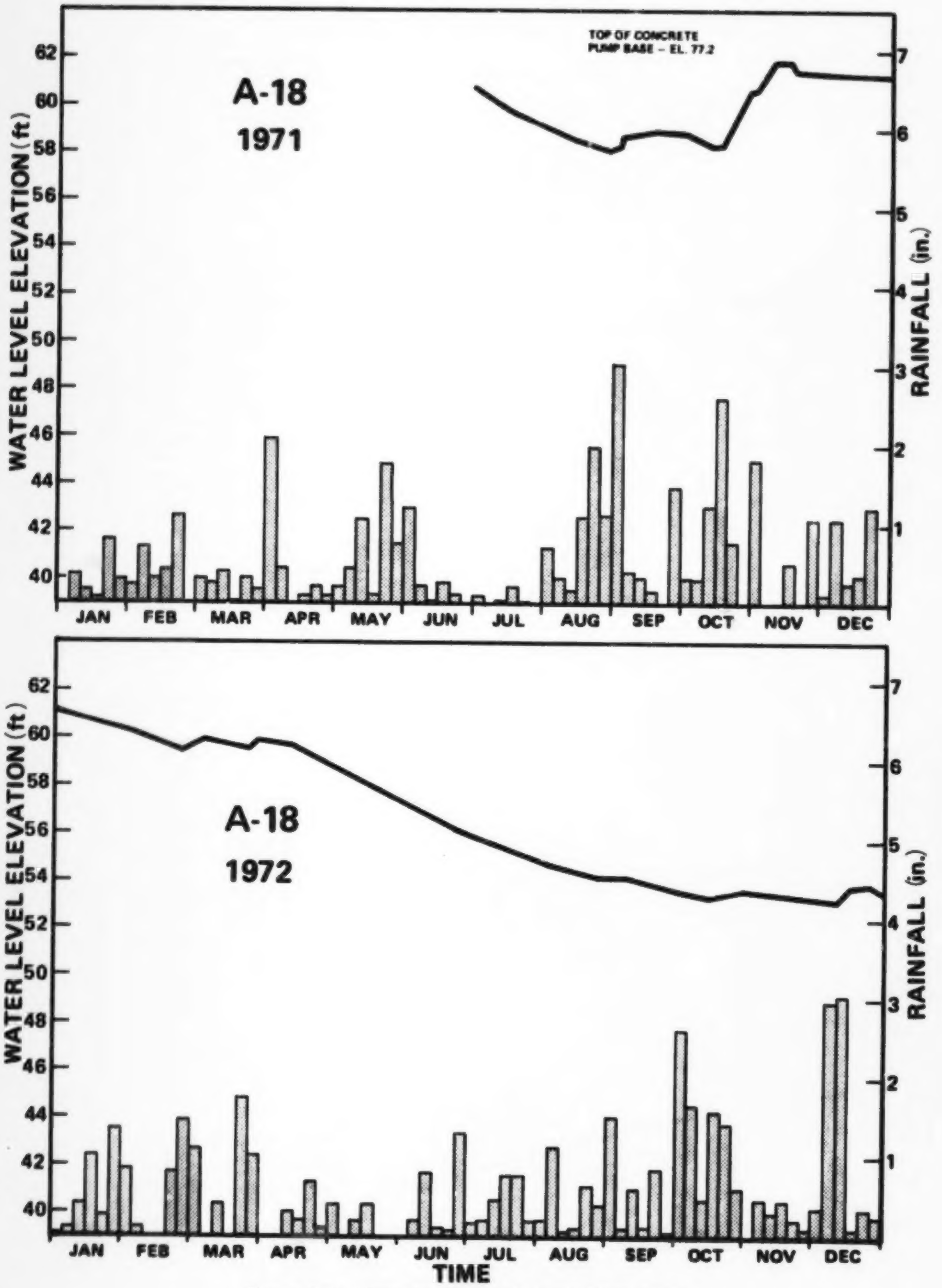

Figure G-4. Water levels in well A-18, 1971-1972.

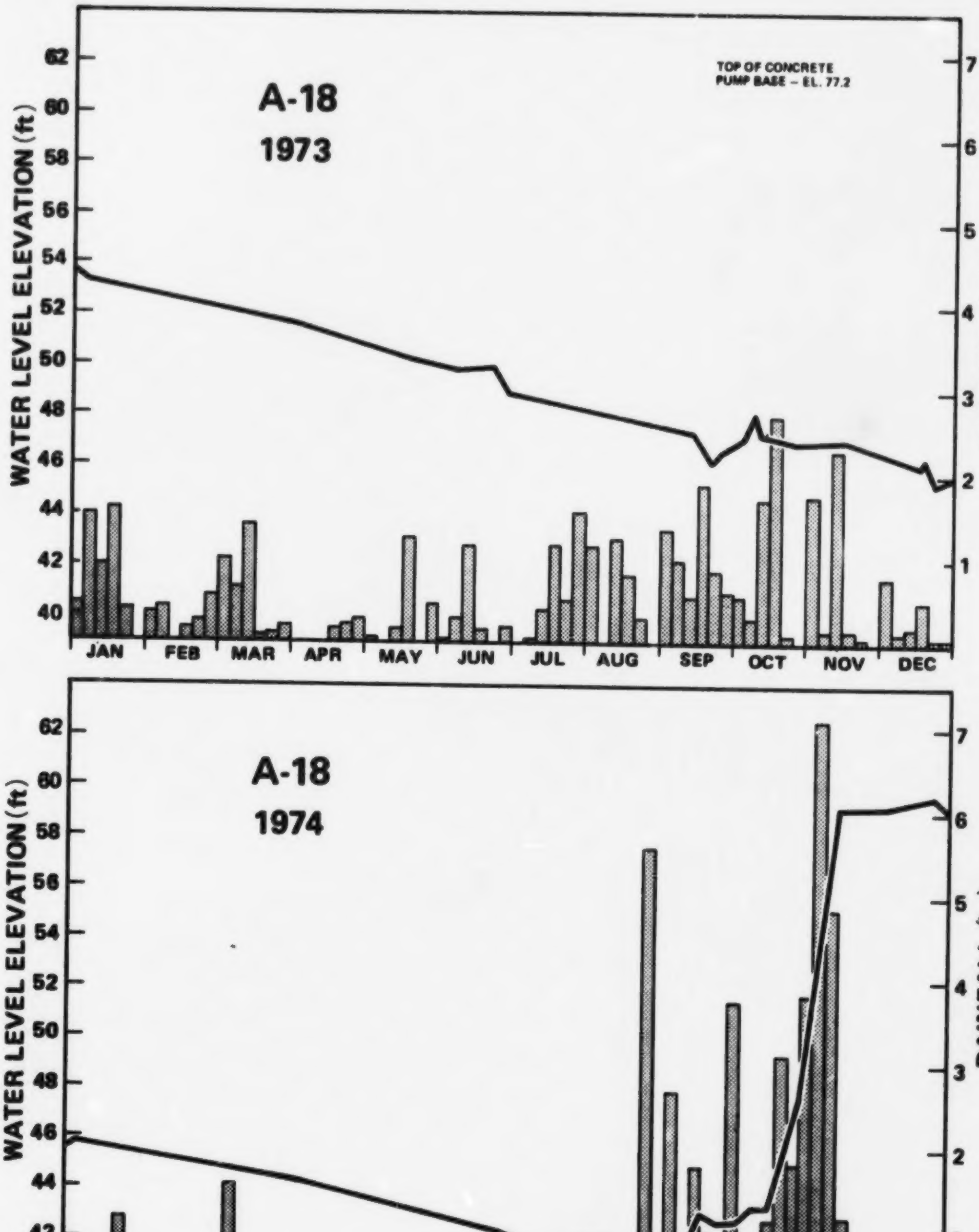

Figure G-5. Water levels in well A-18, 1973-1974.

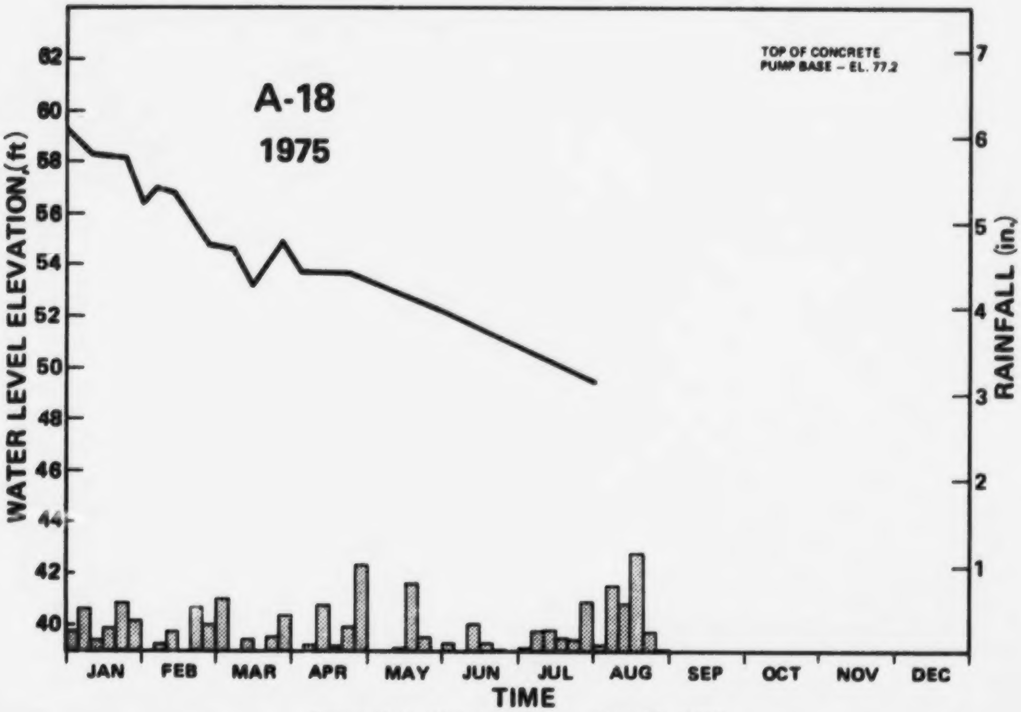

Figure G-6. Water levels in well A-18, 1975.

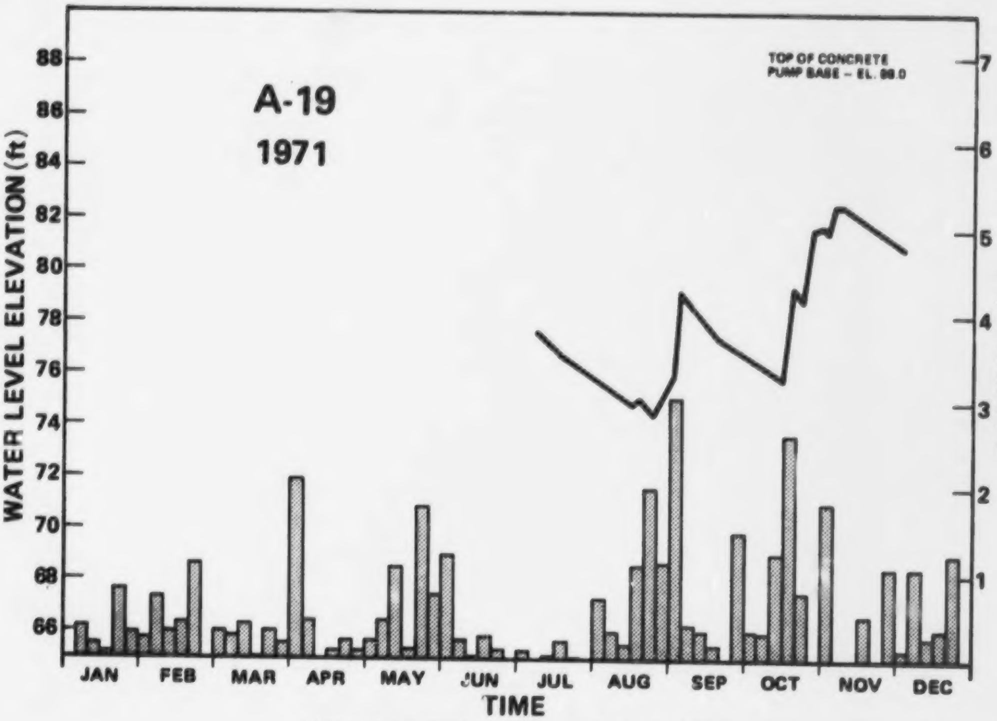

Figure G-7. Water levels in well A-19, 1971.

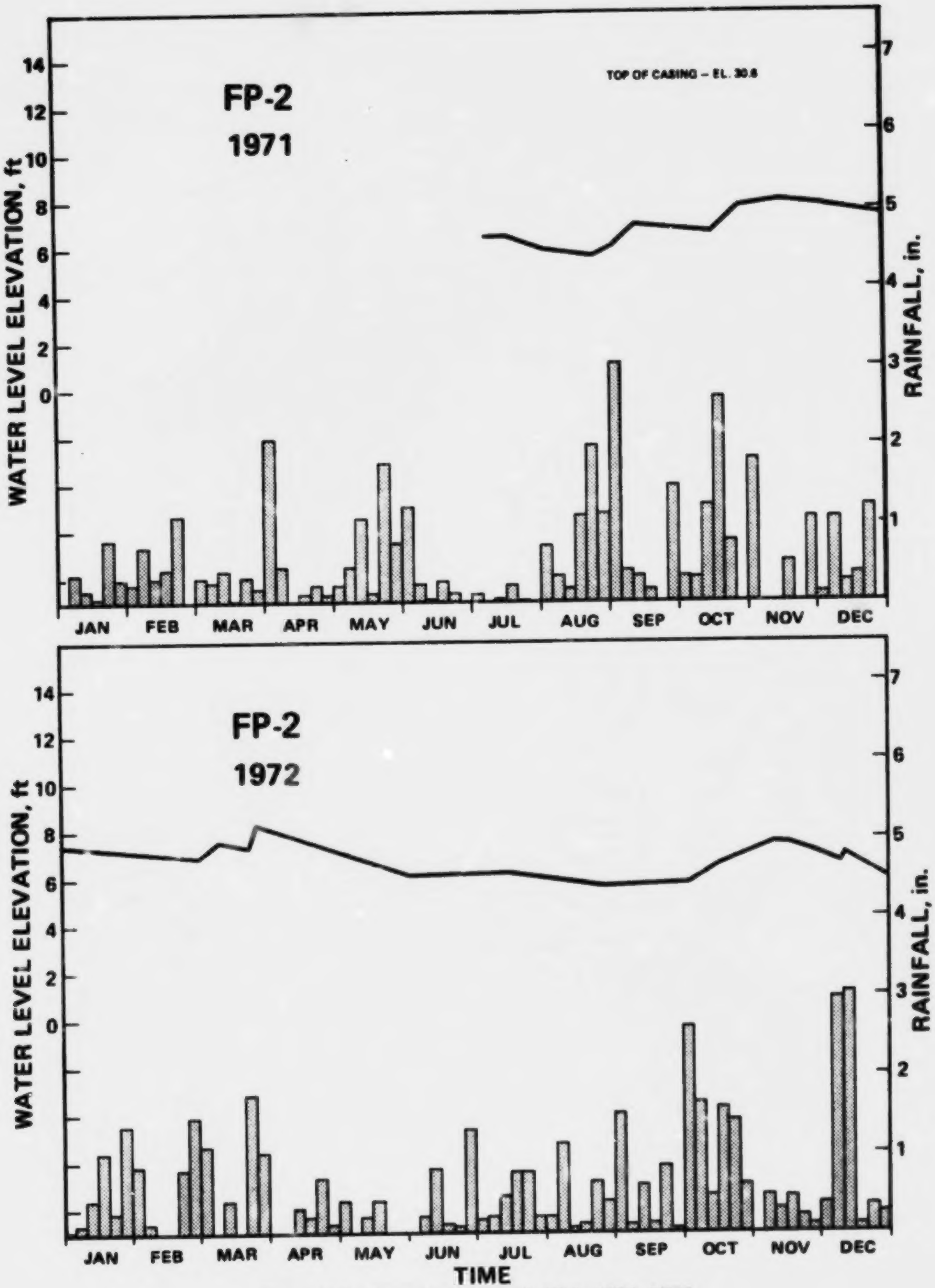

Figure G-8. Water levels in well FP-2, 1971–1972.

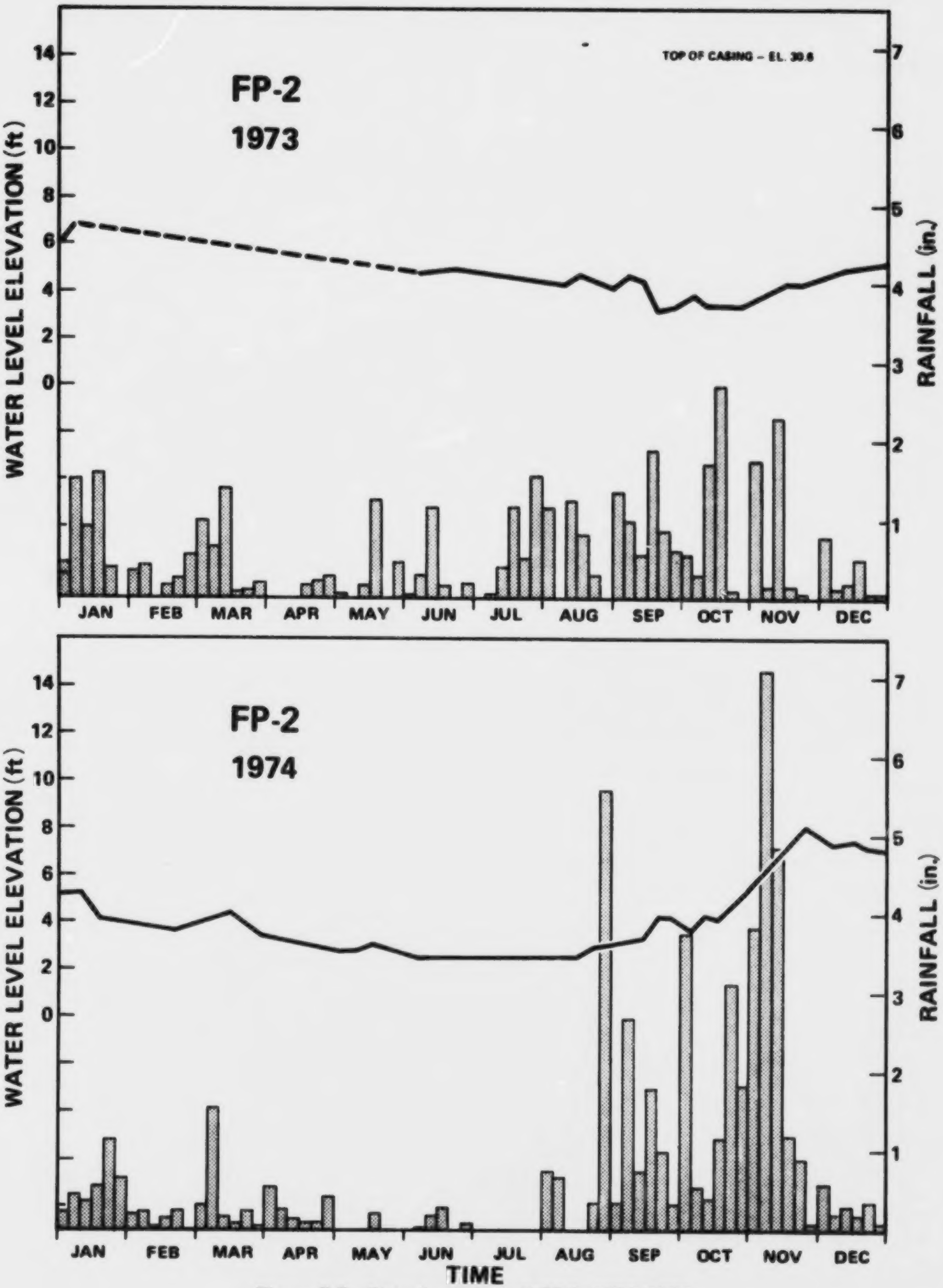

Figure G-9. Water levels in well FP-2, 1973-1974.

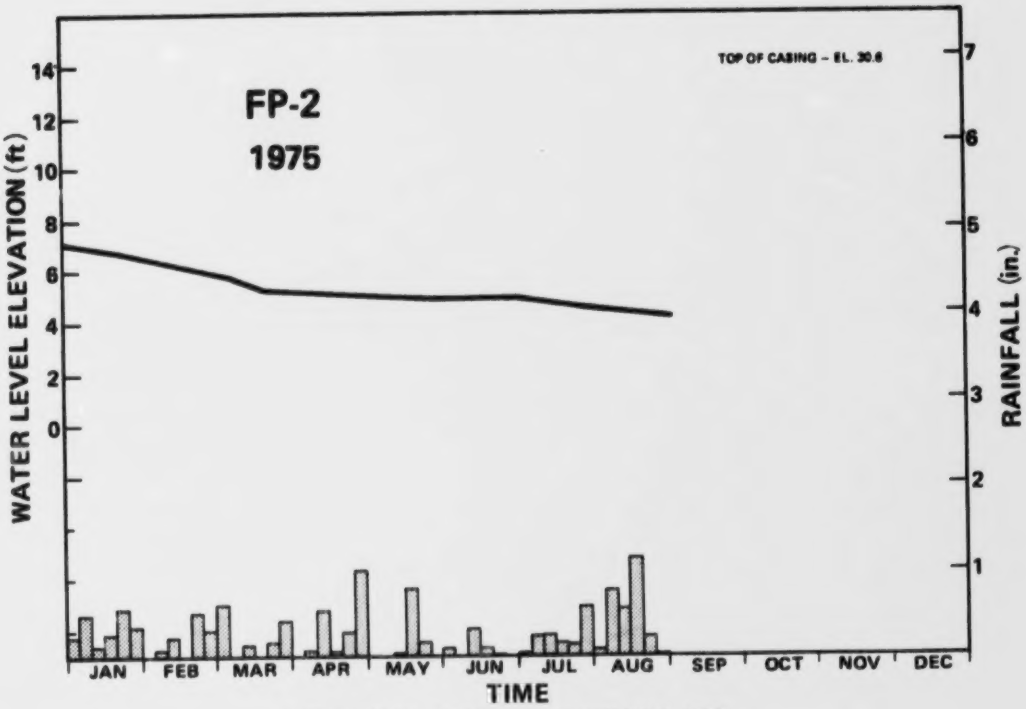

Figure G-10. Water levels in well FP-2, 1975.

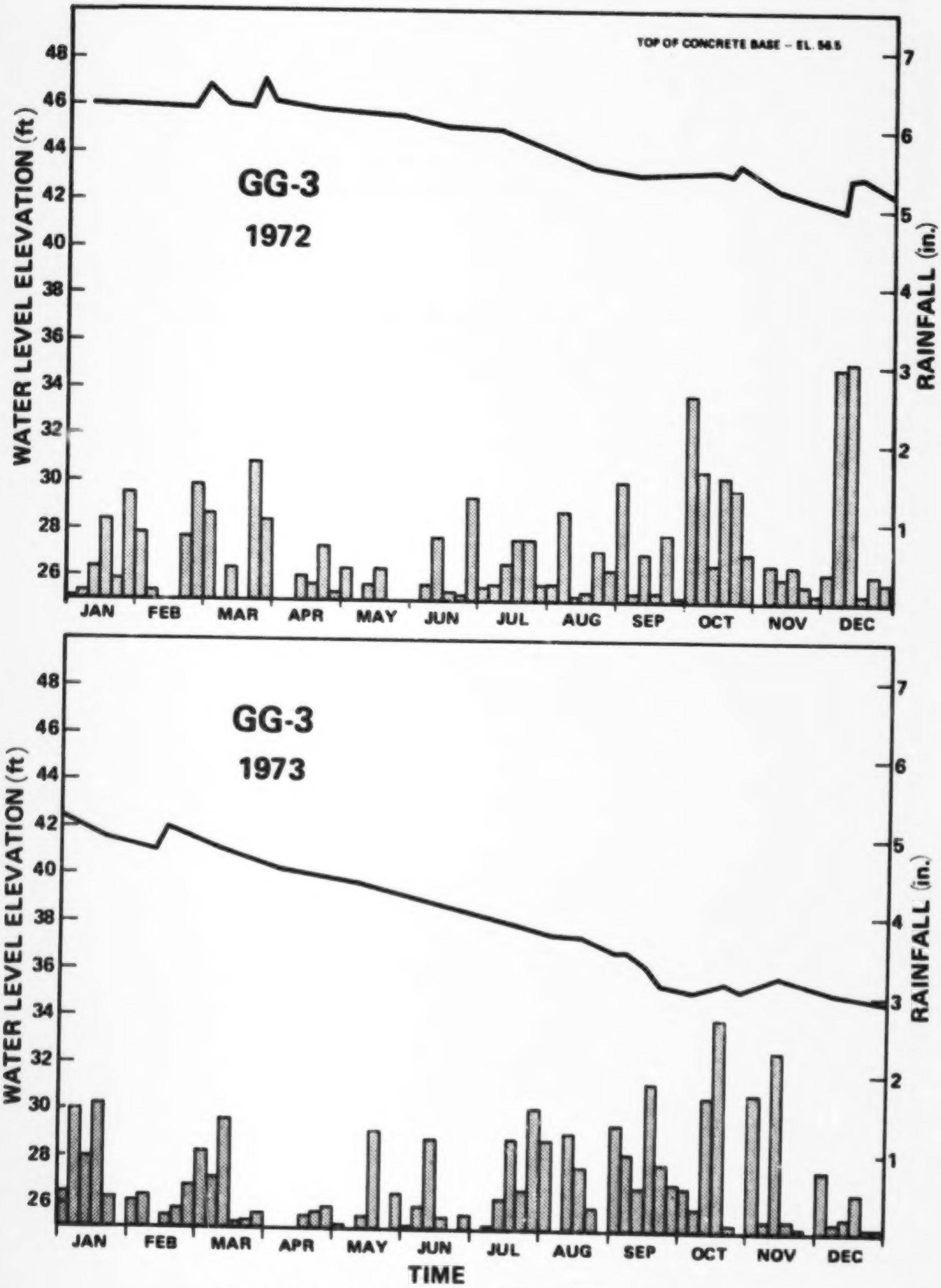

Figure G-11. Water levels in well GG-3, 1972-1973.

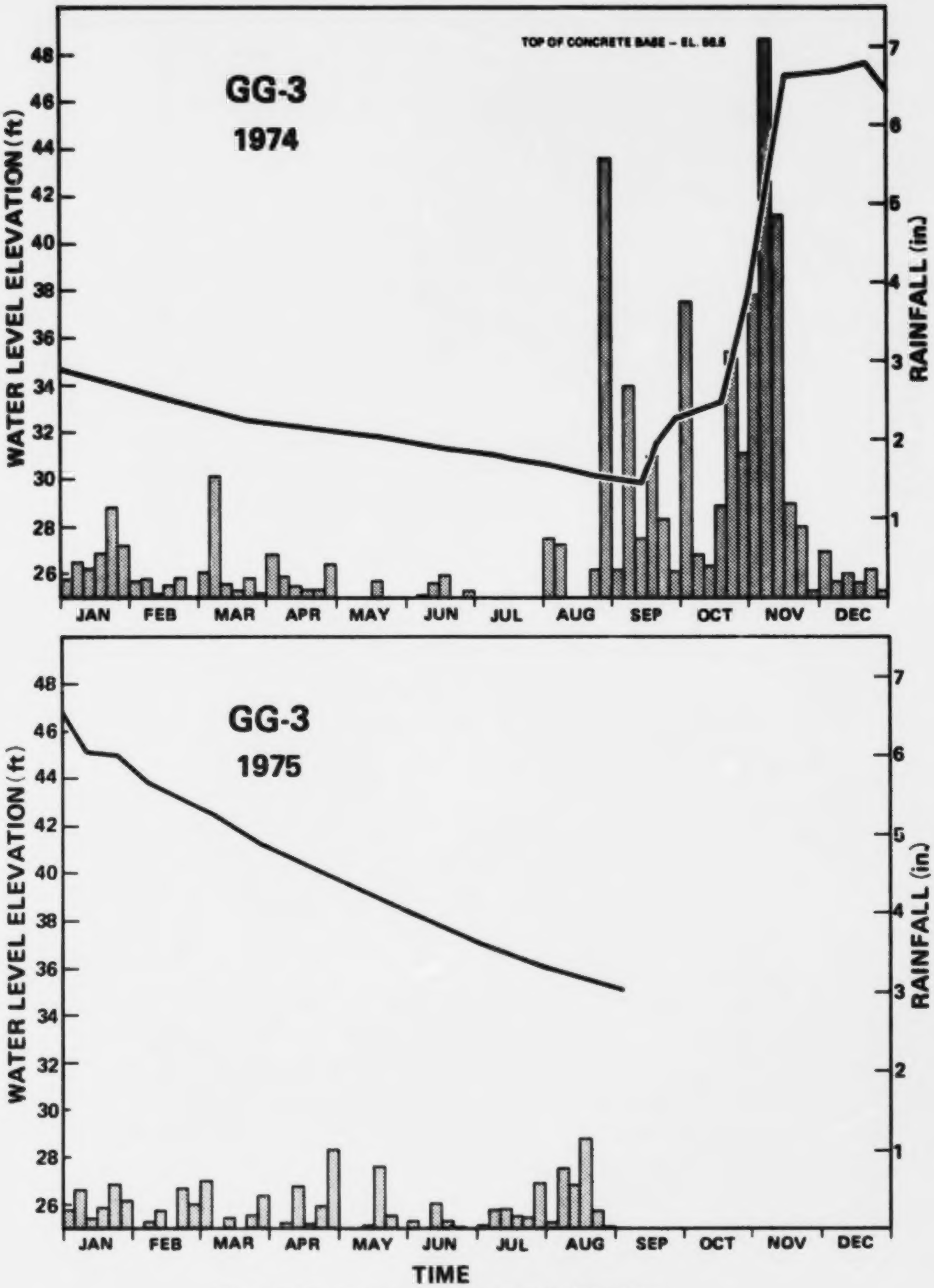

Figure G-12. Water levels in well GG-3, 1974-1975.

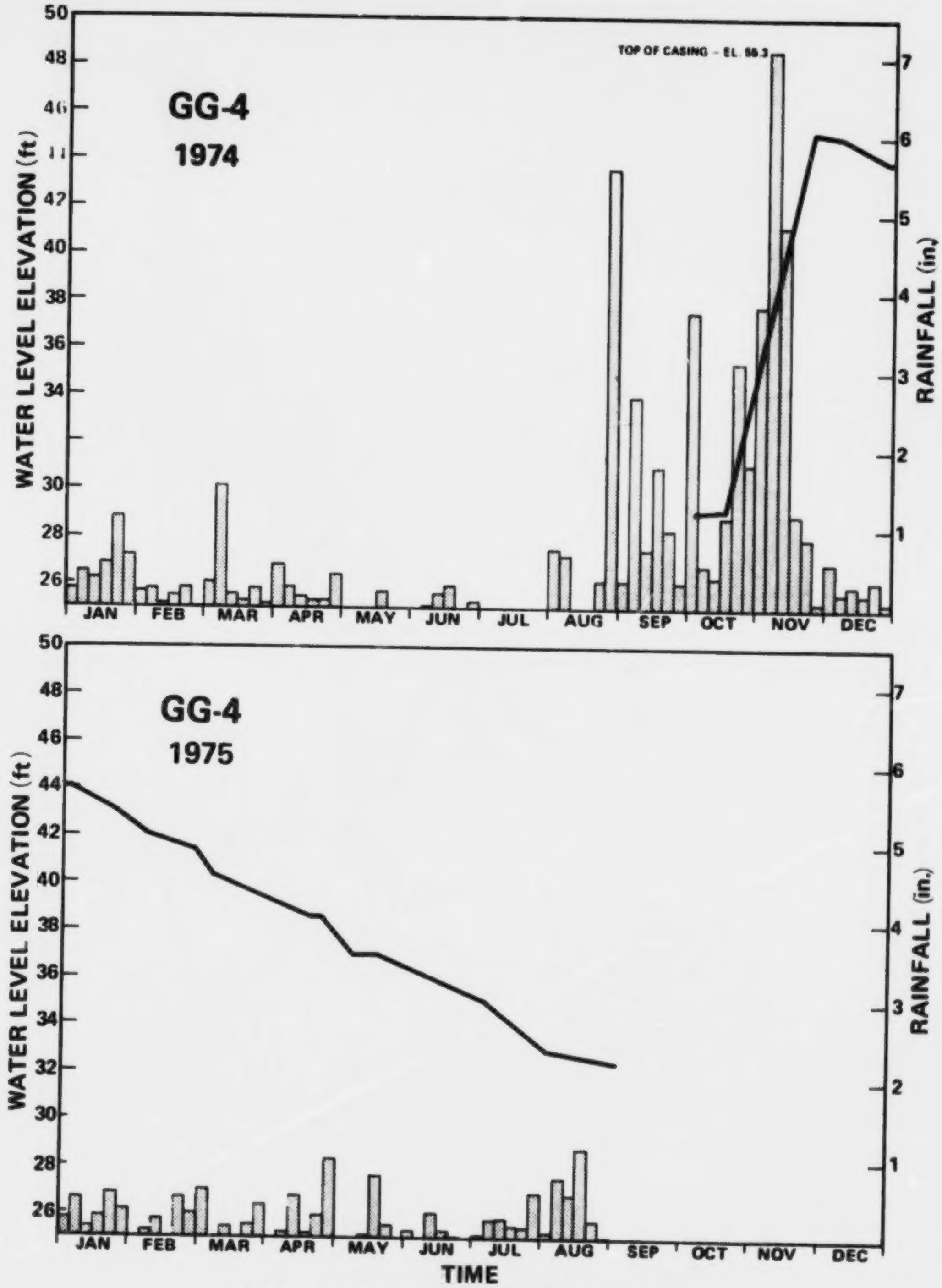

Figure G-13. Water levels in well GG-4, 1974-1975.

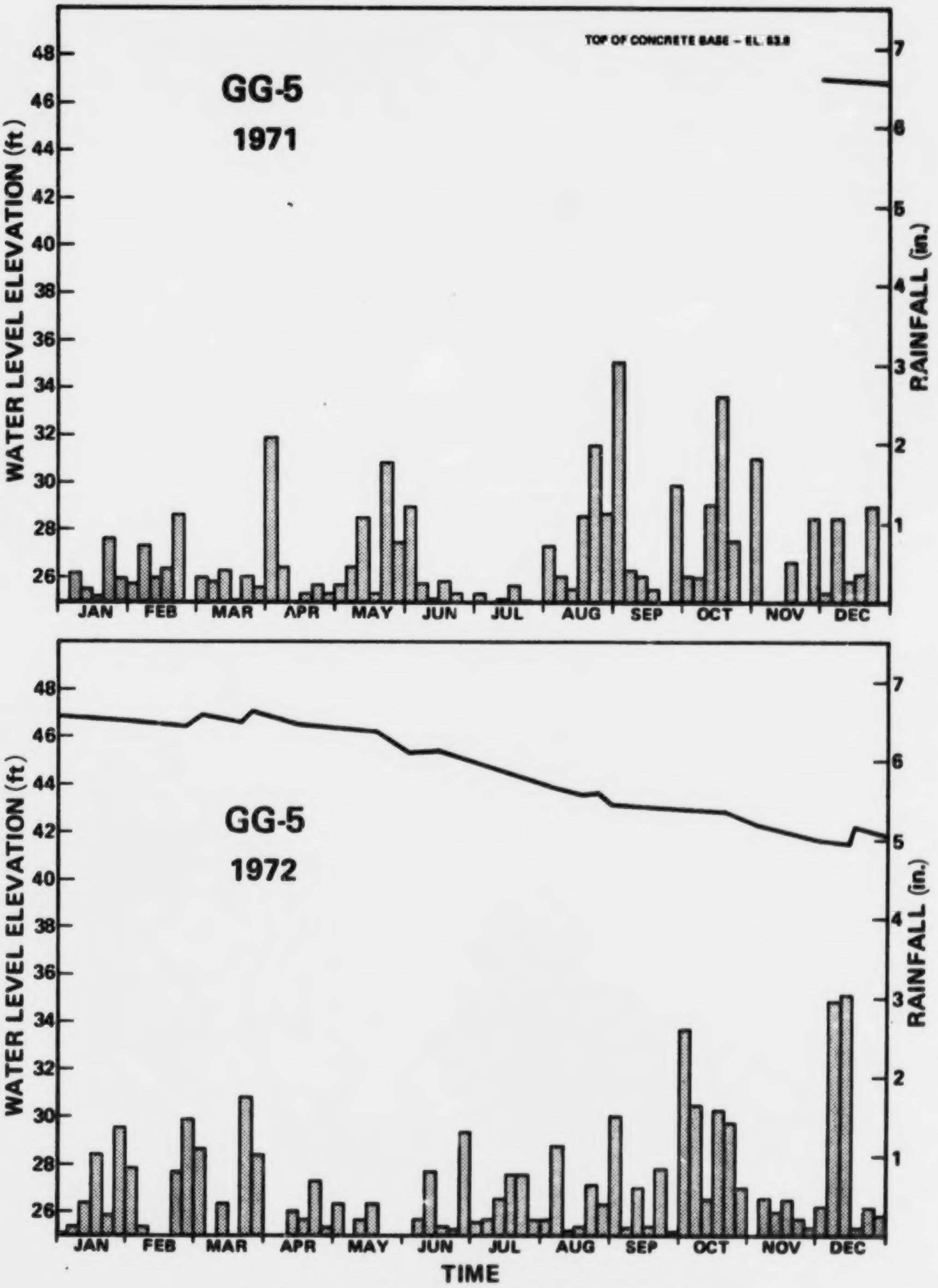

Figure G-14. Water levels in well GG-5, 1971-1972.

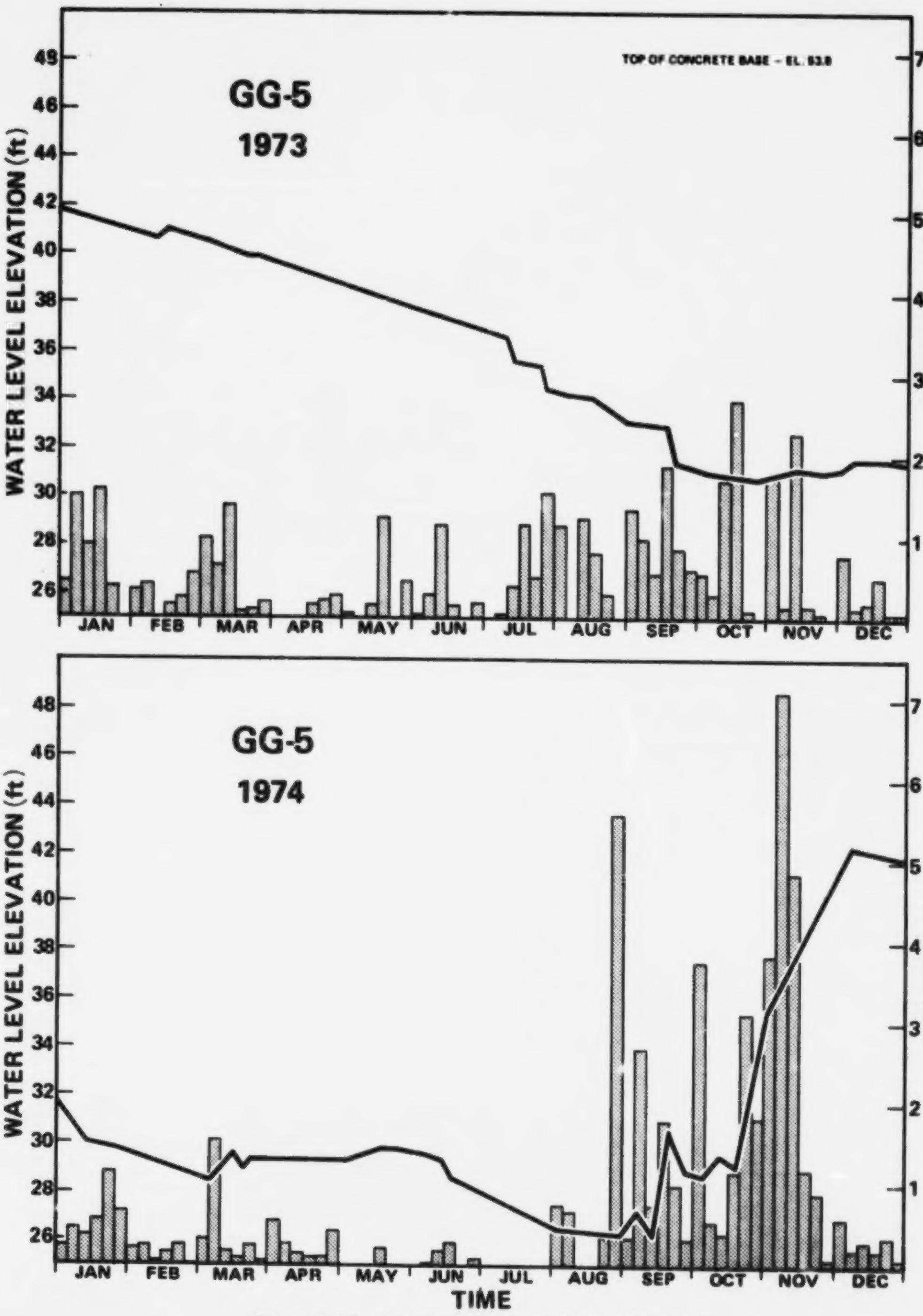

Figure G-15. Water levels in well GG-5, 1973-1974.

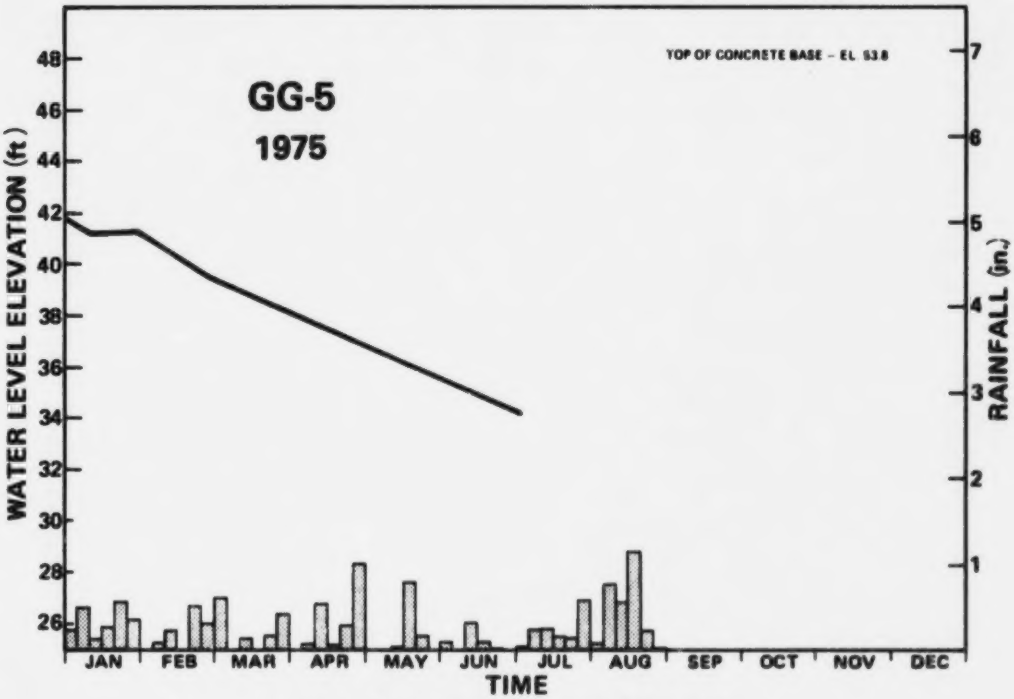

Figure G-16. Water levels in well GG-5, 1975.

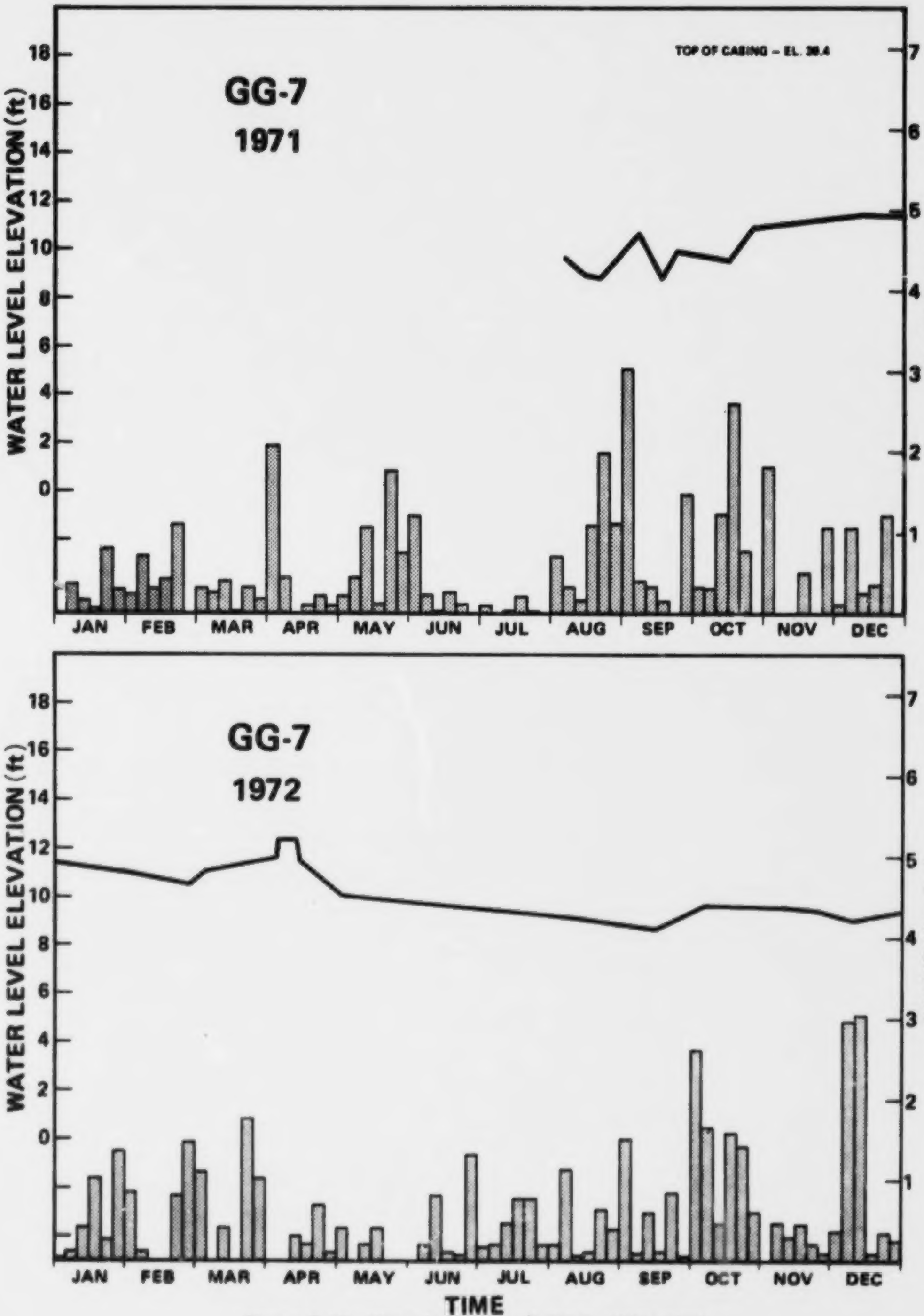

Figure G-17. Water levels in well GG-7, 1971-1972.

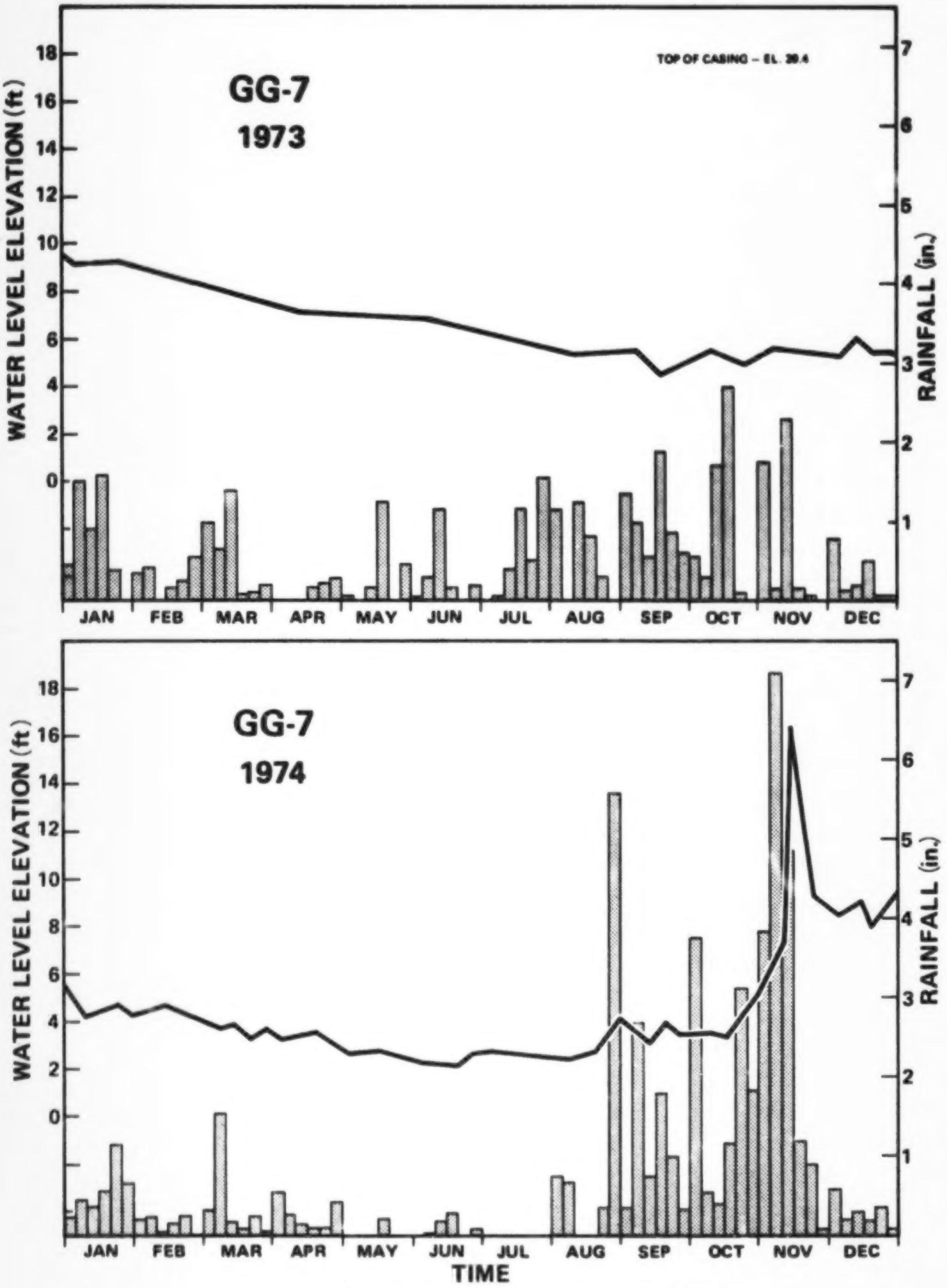

Figure G-18. Water levels in well GG-7, 1973-1974.

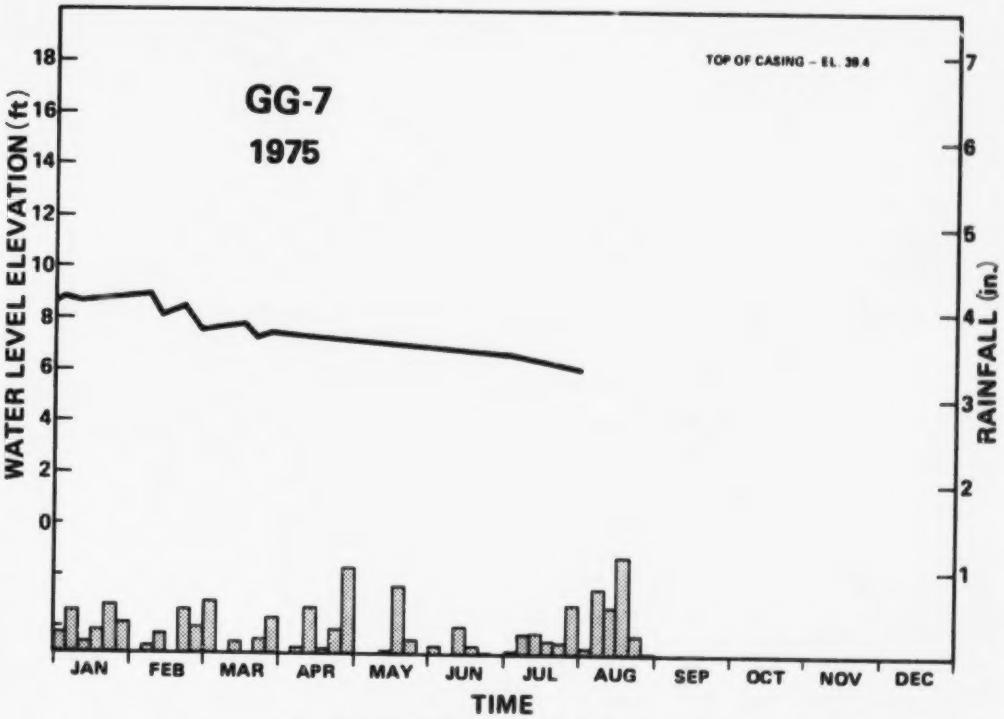

Figure G-19. Water levels in well GG-7, 1975.

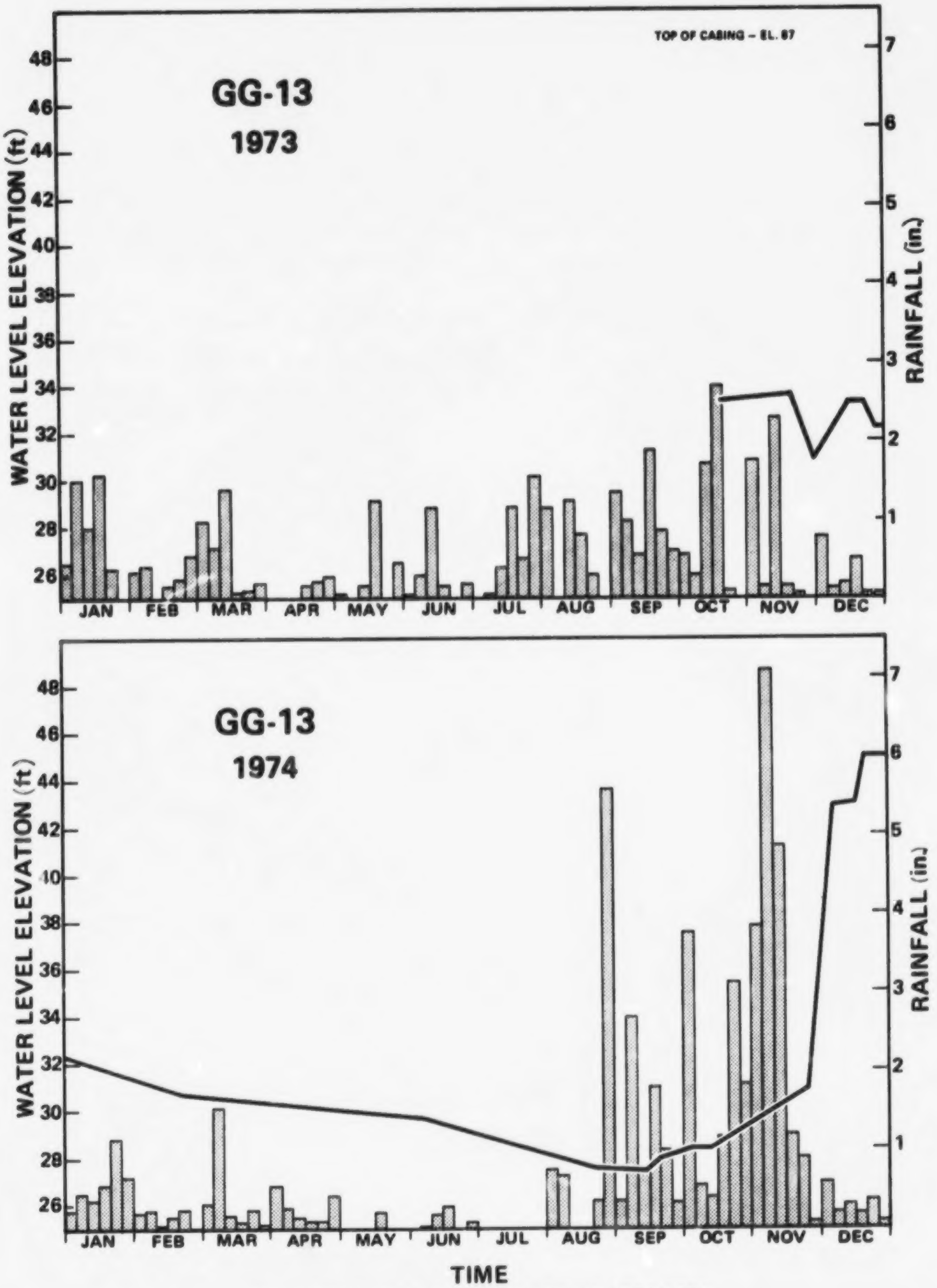

Figure G-20. Water levels in well GG-13, 1973-1974.

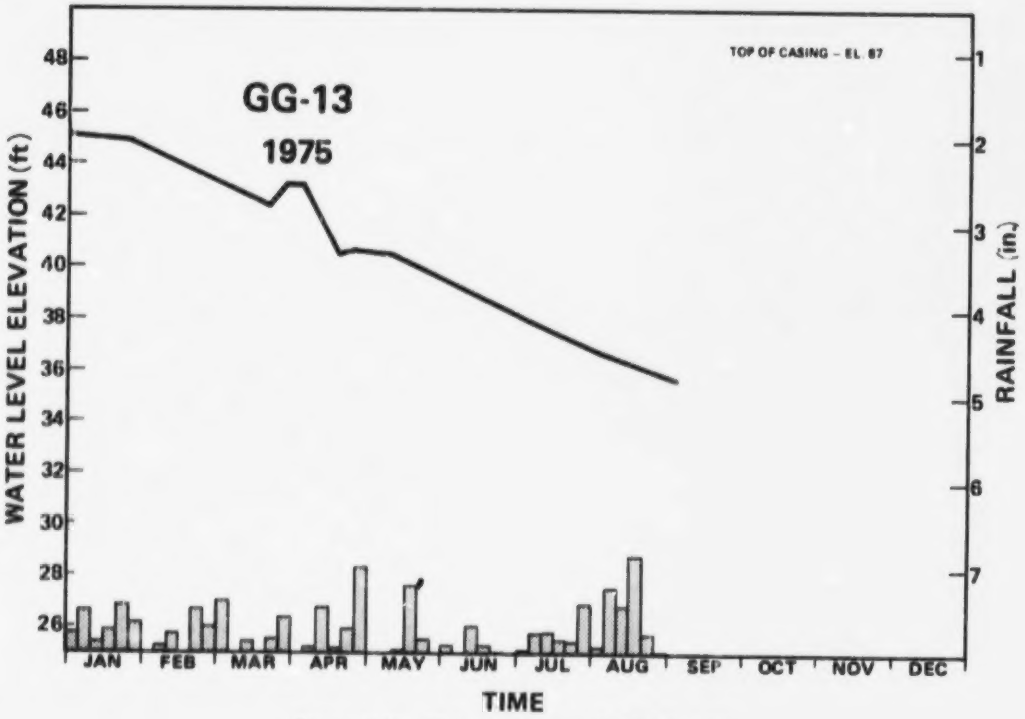

Figure G-21. Water levels in well GG-13, 1975.

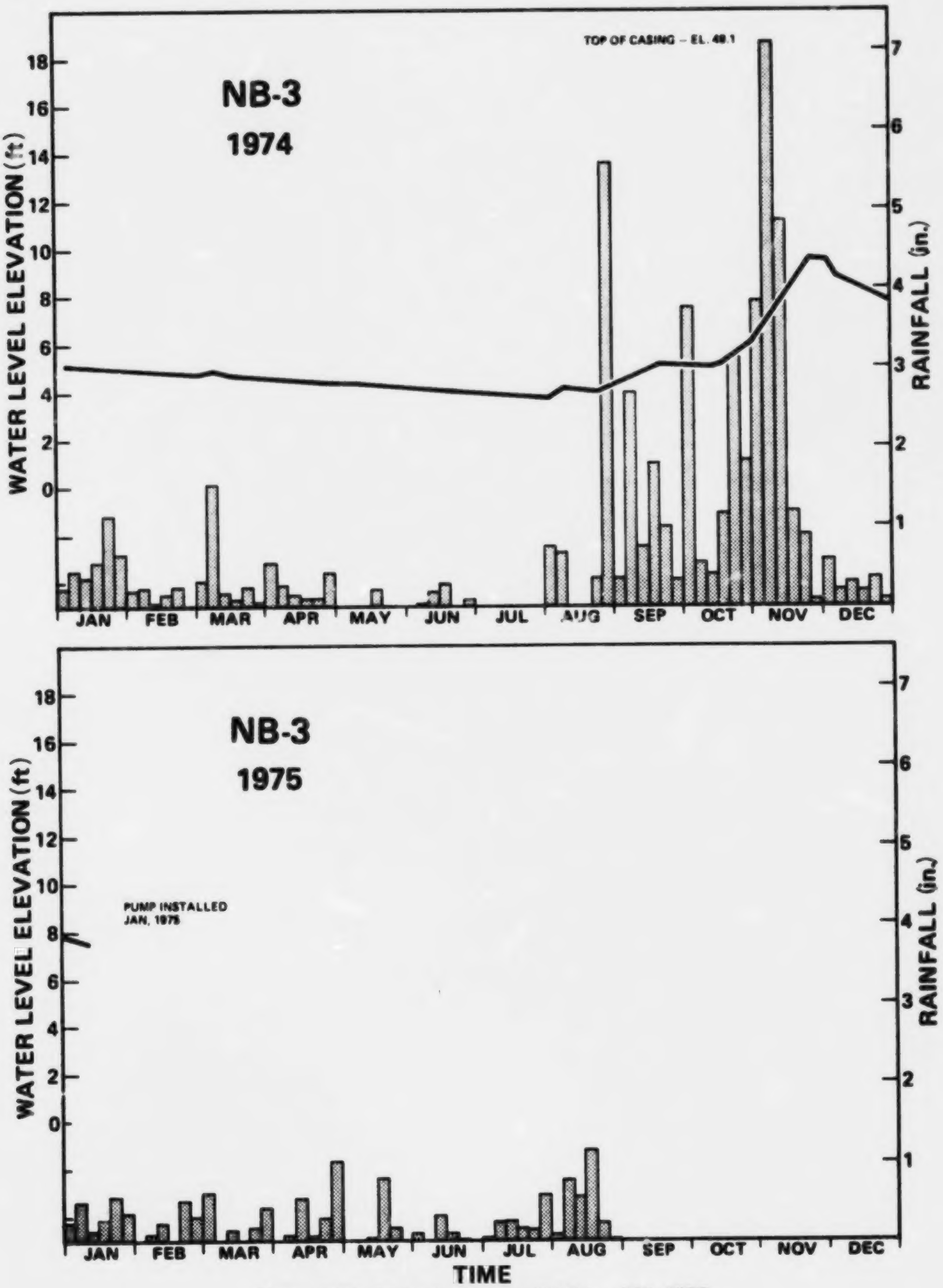

Figure G-22. Water levels in well NB-3, 1974-1975.

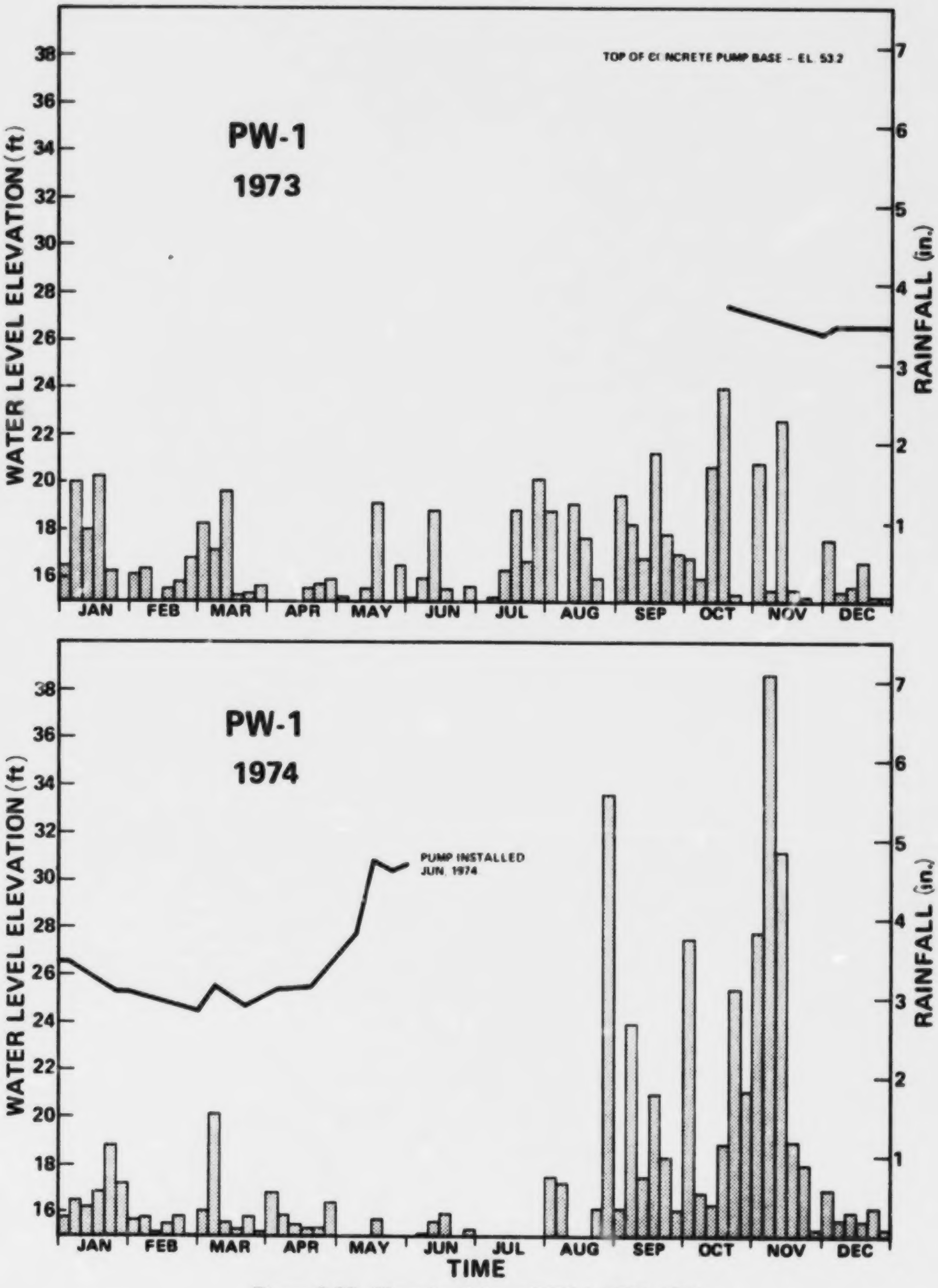

Figure G-23. Water levels in well PW-1, 1973–1974.

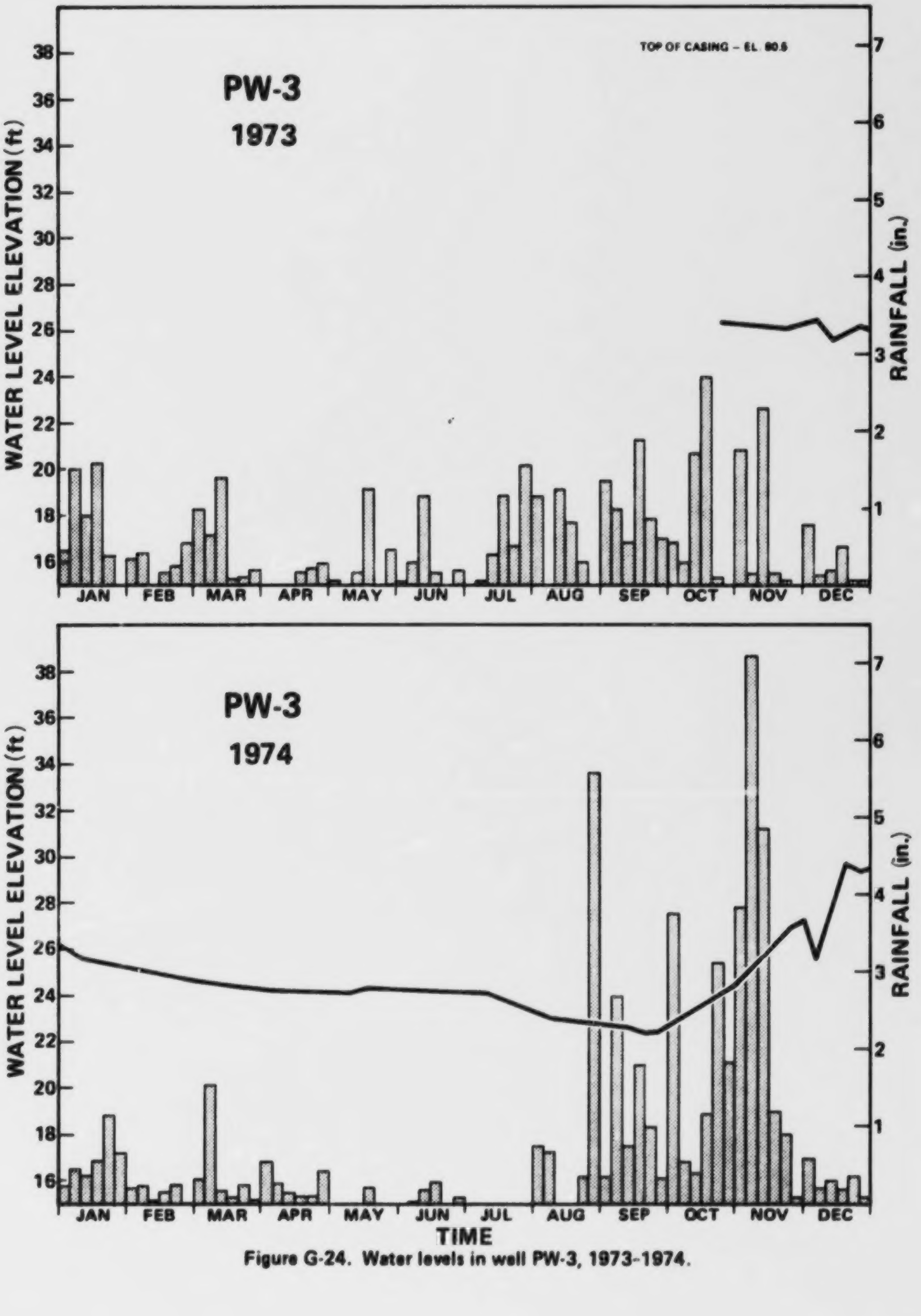

Figure G-24. Water levels in well PW-3, 1973-1974.

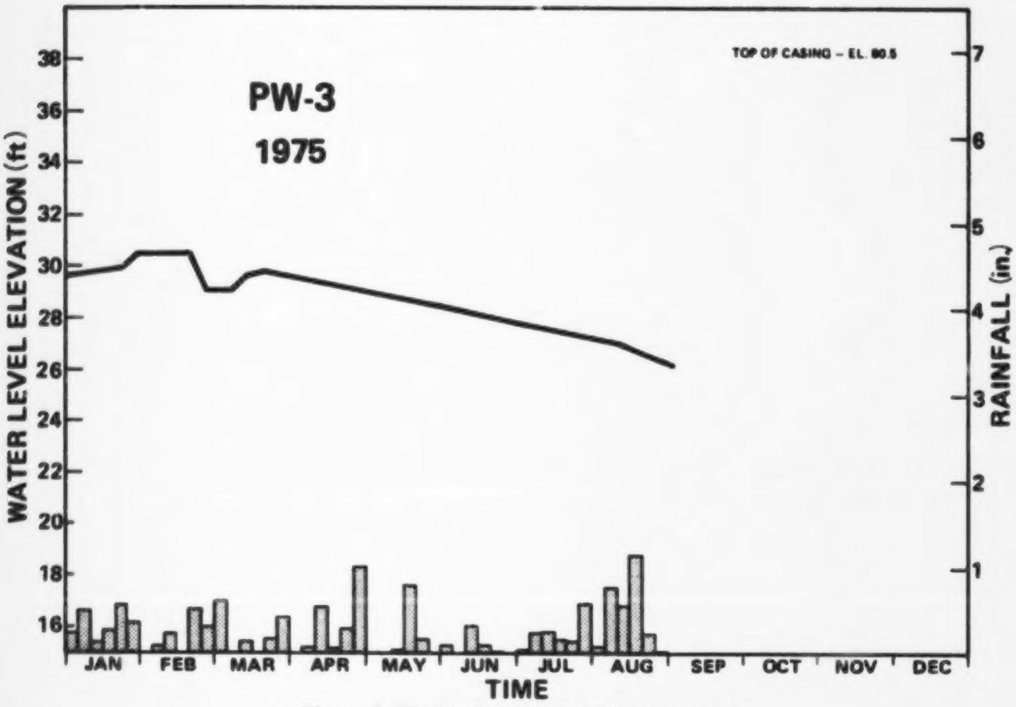

Figure G-25. Water levels in well PW-3, 1975.

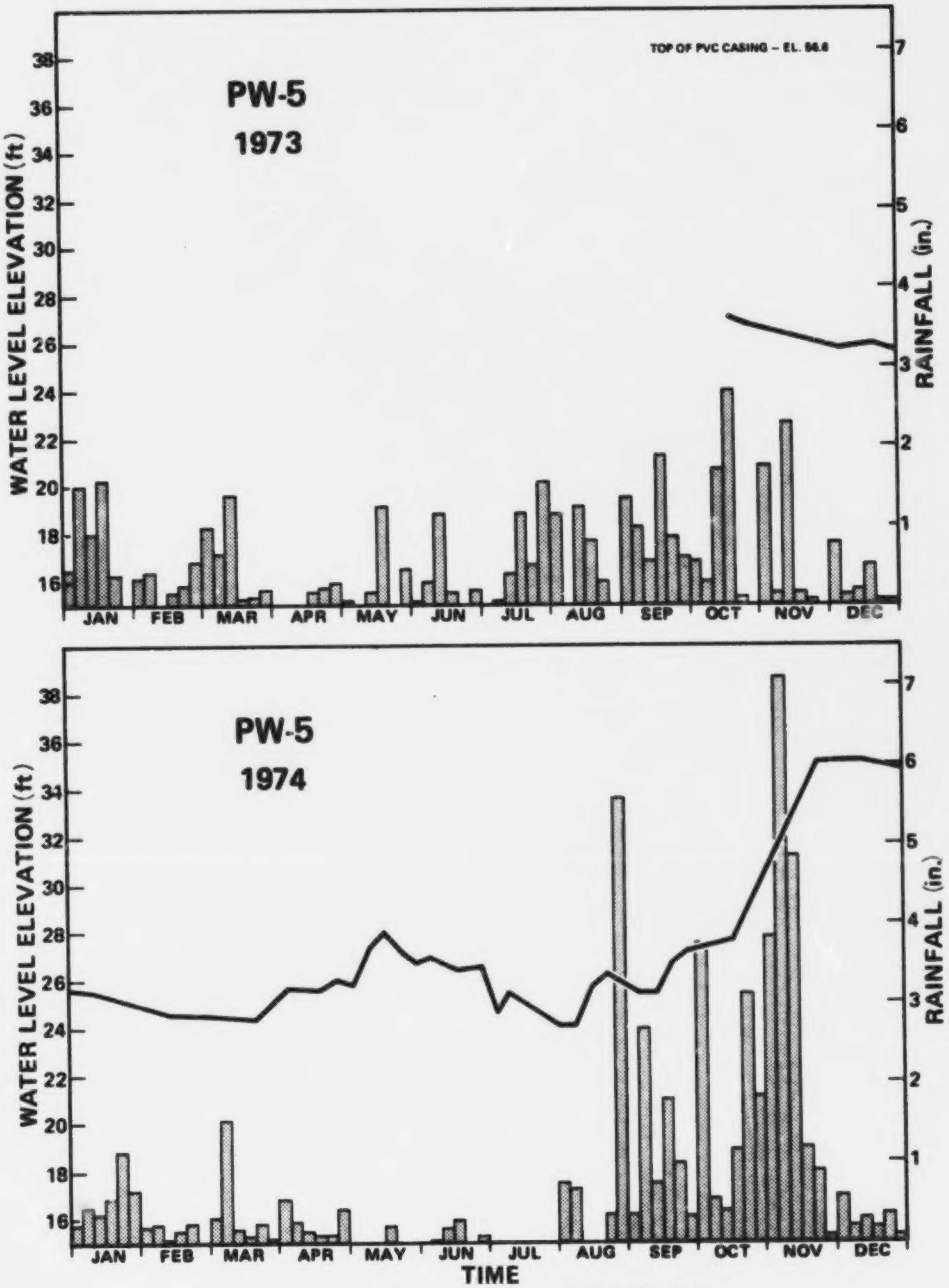

Figure G-26. Water levels in well PW-5, 1973-1974.

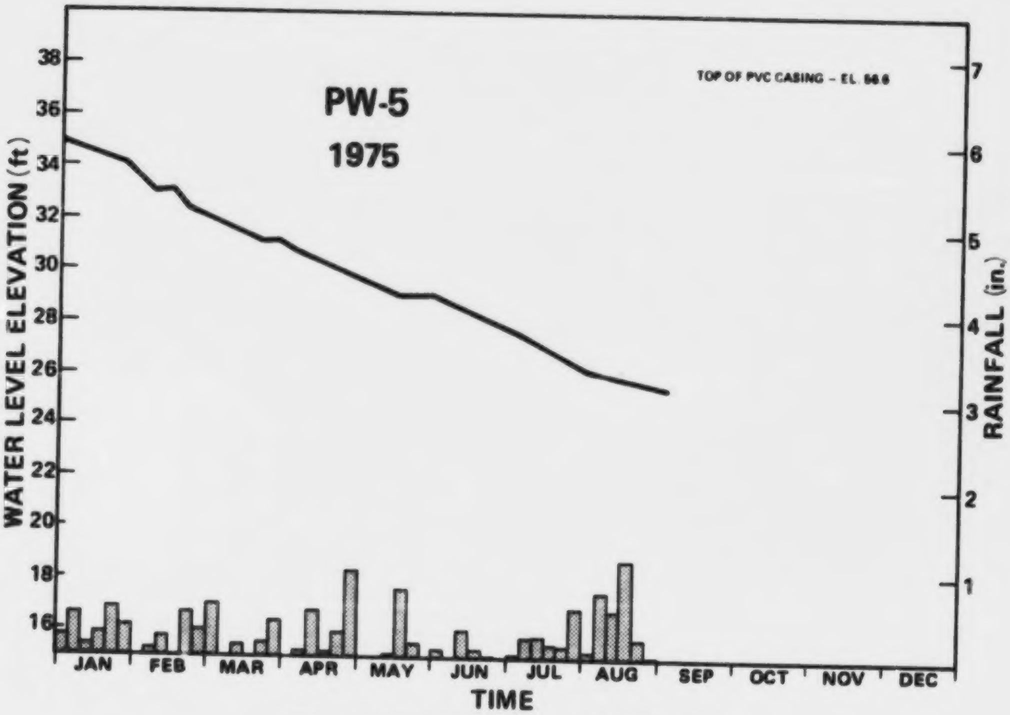

Figure G-27. Water levels in well PW-5, 1975.

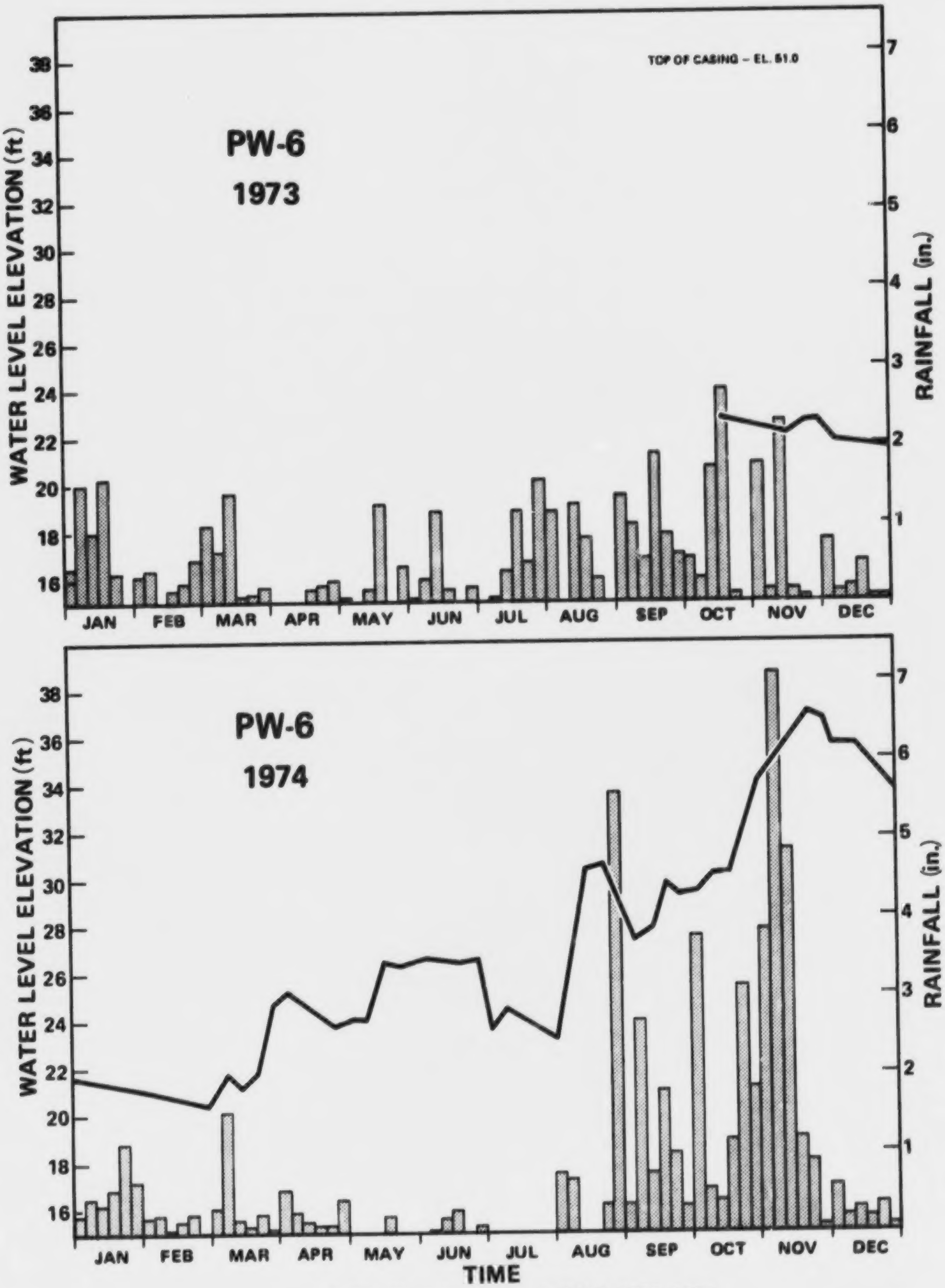

Figure G-28. Water levels in well PW-6, 1973-1974.

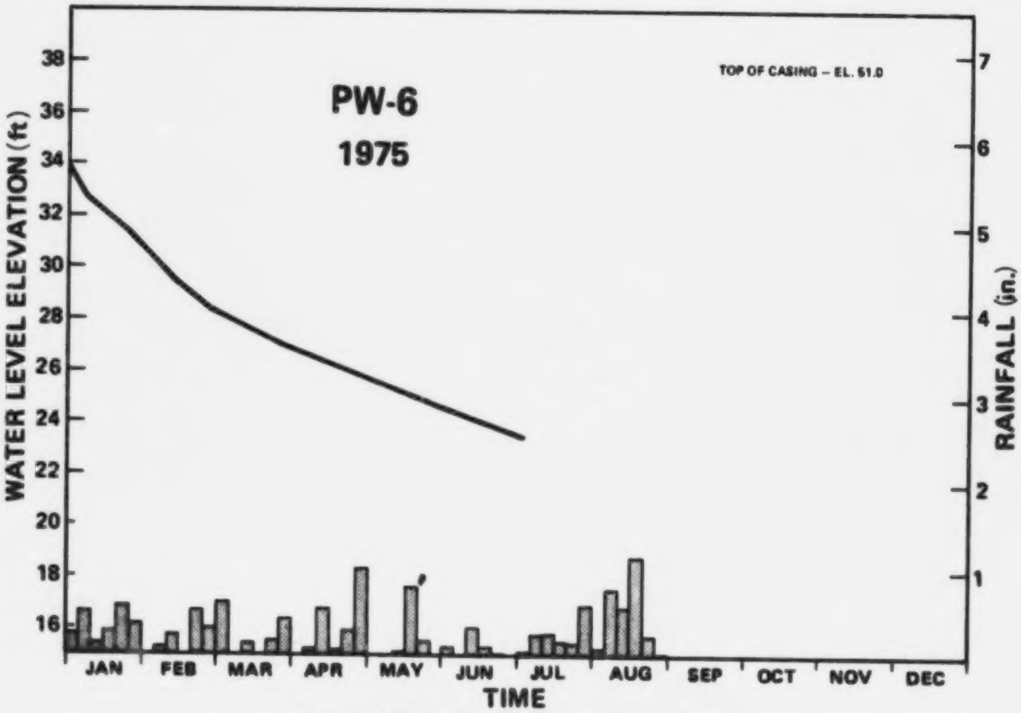

Figure G-29. Water levels in well PW-6, 1975.

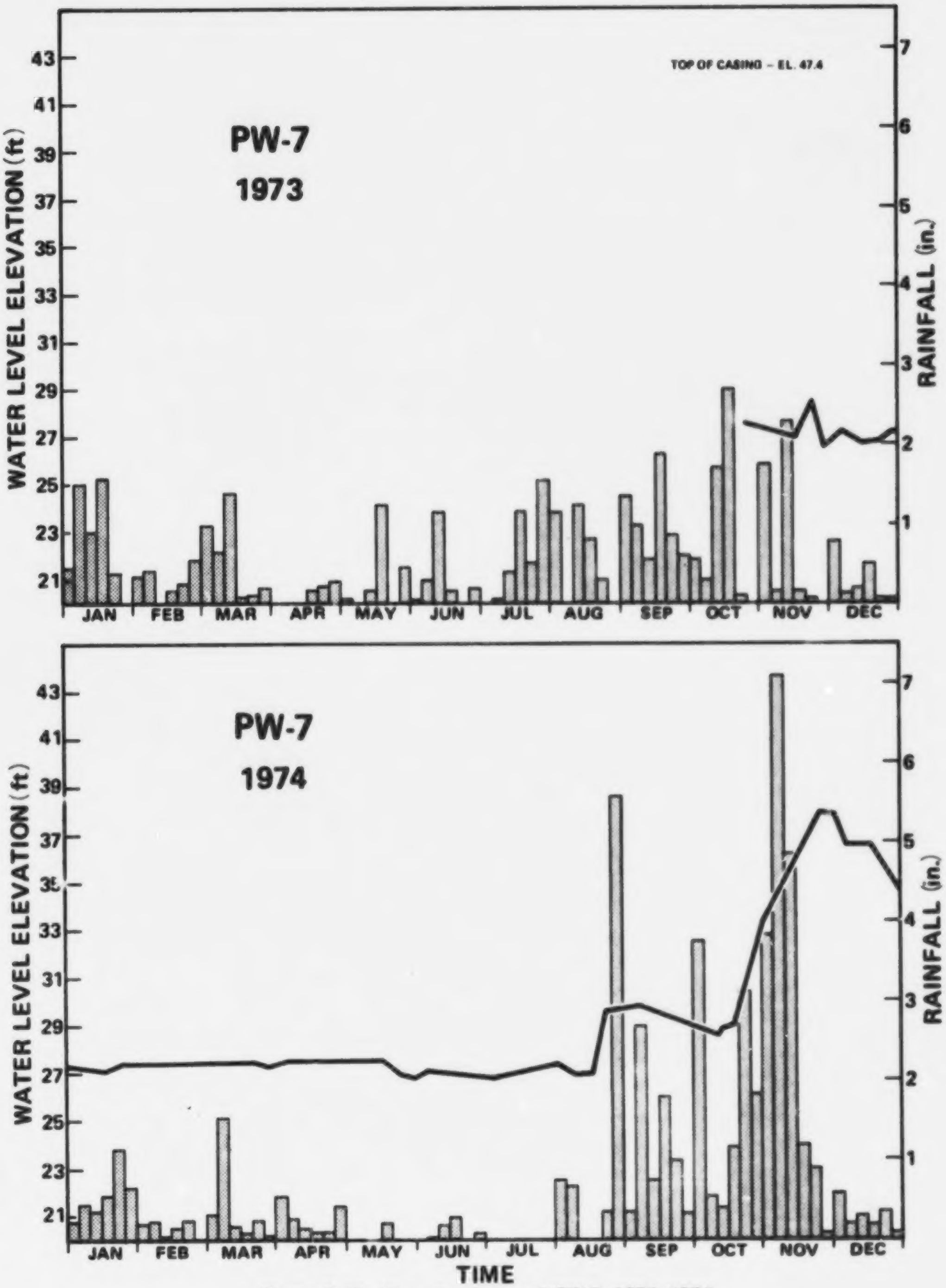

Figure G-30. Water levels in well PW-7, 1973-1974.

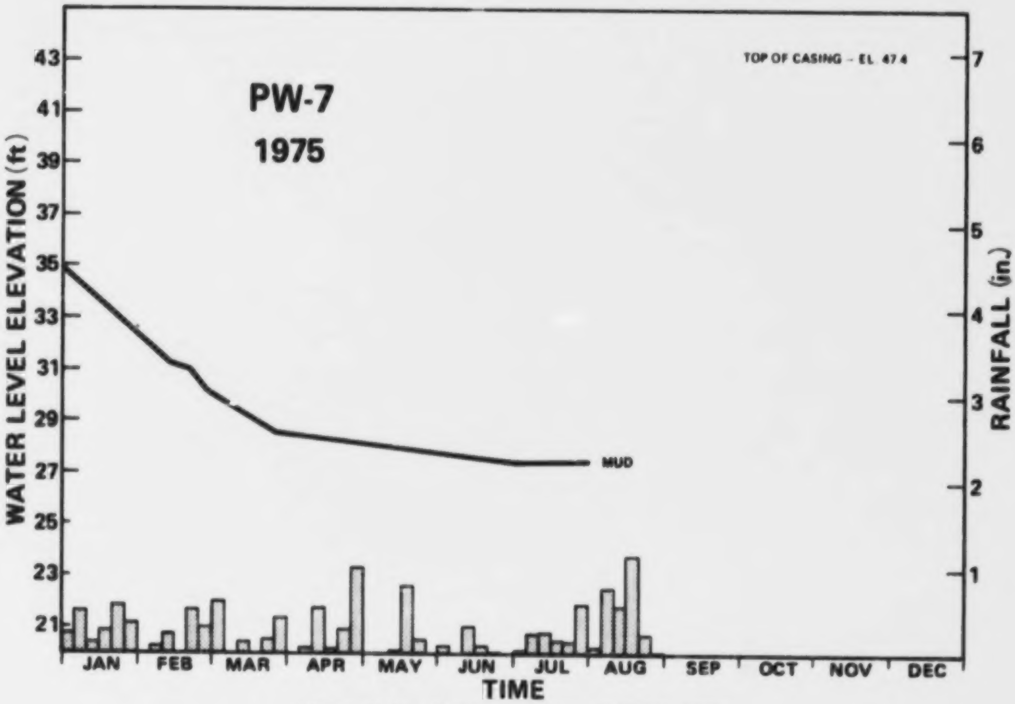

Figure G-31. Water levels in well PW-7, 1975.

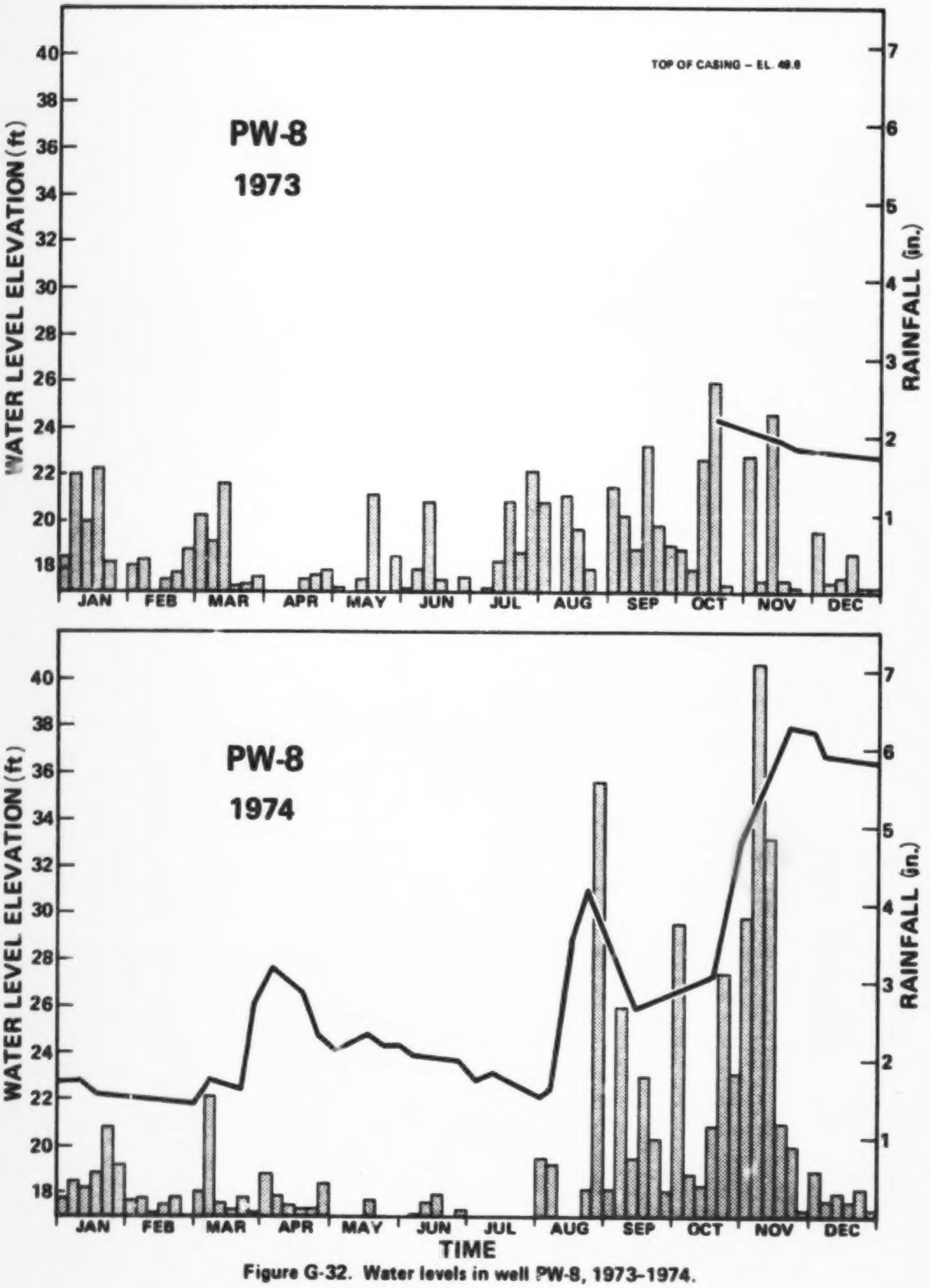

Figure G-32. Water levels in well PW-8, 1973-1974.

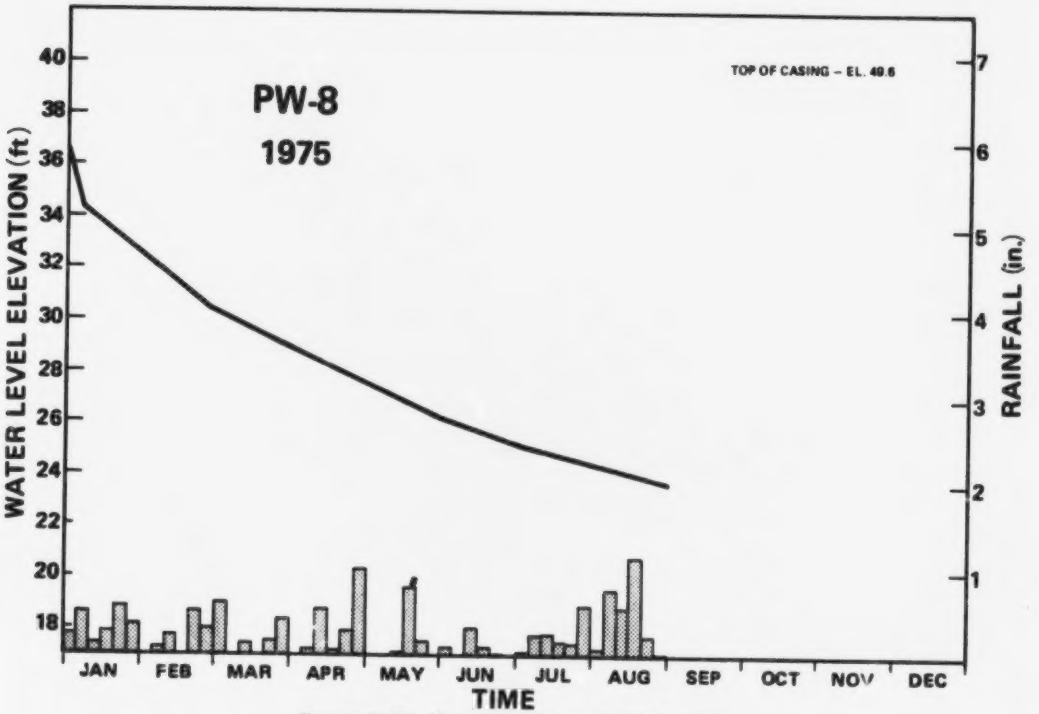

Figure G-33. Water levels in well PW-8, 1975.

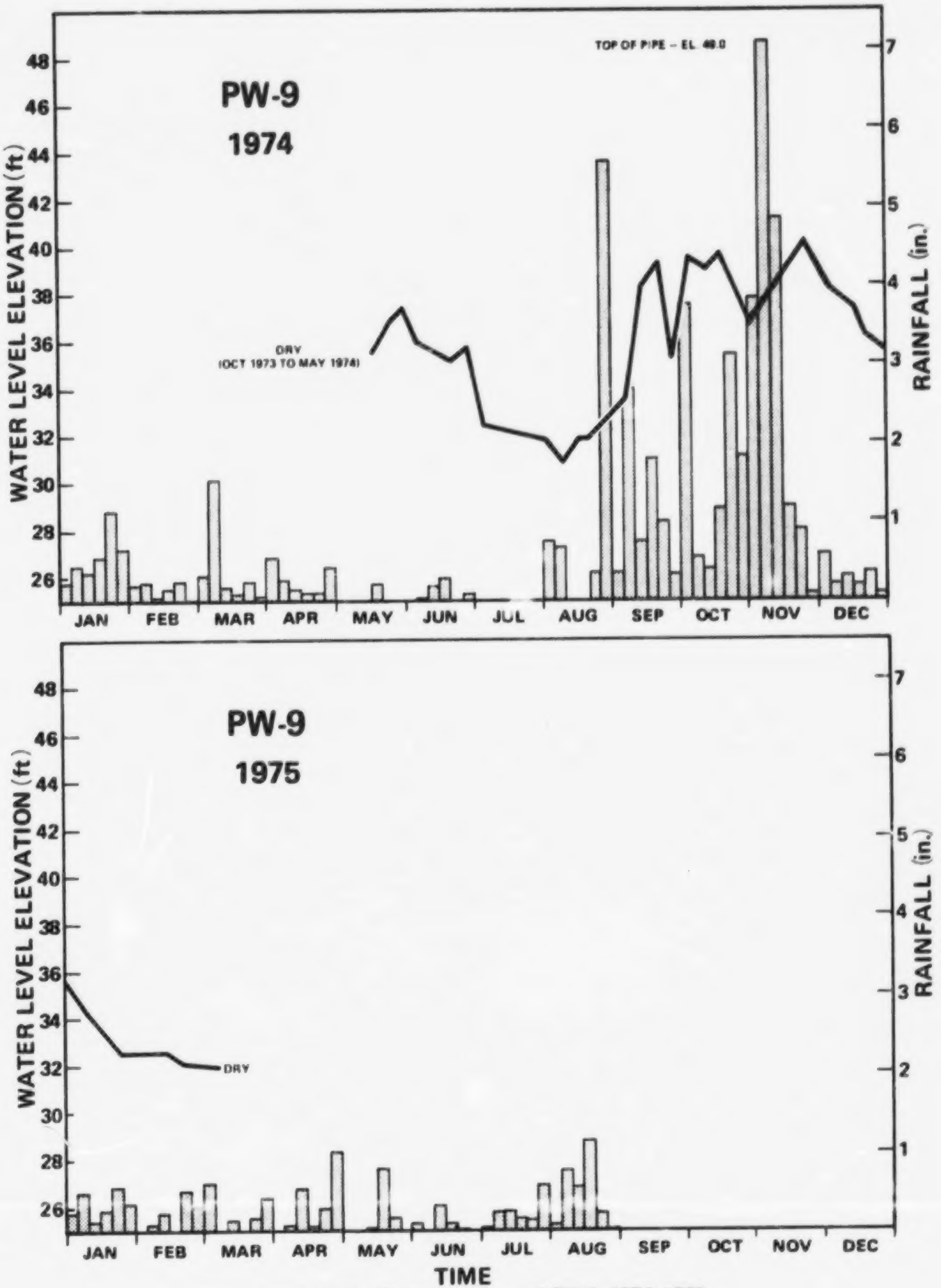

Figure G-34. Water levels in well PW-9, 1974-1975.

APPENDIX - PART H

TABLE H-1. ENGLISH-TO-METRIC CONVERSION

English unit	Multiplier	Metric unit
acre	0.405	ha
acre-ft	1,233.5	cu m
cu ft	0.028	cu m
ft	0.3048	m
gal	0.003785	cu m
gal	3.785	l
gpd/sq ft	0.0408	cu m/day/sq m
gpm	0.0631	l/sec
hp	0.7457	kw
in.	2.54	cm
lb	0.454	kg
mgd	3,785	cu m/day
mile	1.61	km
sq ft	0.0929	sq m
sq in.	6.452	sq cm
sq miles	2.590	sq km